US007521826B2

(12) **United States Patent**
Hempe et al.

(10) **Patent No.: US 7,521,826 B2**
(45) **Date of Patent: Apr. 21, 2009**

(54) **POWER TOOLS WITH SWITCHED RELUCTANCE MOTOR**

(75) Inventors: **David A. Hempe**, Wauwatosa, WI (US); **Gary D. Meyer**, Waukesha, WI (US); **Roderick N. Ebben**, Dousman, WI (US); **Jeffrey M. Brozek**, Whitefish Bay, WI (US)

(73) Assignee: **Milwaukee Electric Tool Corporation**, Brookfield, WI (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **11/331,477**

(22) Filed: **Jan. 13, 2006**

(65) **Prior Publication Data**

US 2006/0175913 A1 Aug. 10, 2006

Related U.S. Application Data

(63) Continuation of application No. 10/357,729, filed on Feb. 4, 2003, now Pat. No. 7,064,462.

(60) Provisional application No. 60/354,253, filed on Feb. 4, 2002.

(51) **Int. Cl.**

H02K 3/52	(2006.01)
H02K 5/15	(2006.01)
B27B 5/29	(2006.01)

(52) **U.S. Cl.** .... **310/50**; 310/168; 310/89; 310/68 D; 310/71

(58) **Field of Classification Search** .... 310/166, 310/168, 68 D, 50, 71, 90, 89, 88; 30/388, 30/392; 173/217, 117; 83/478

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,678,352 A		7/1972	Bedford	318/138
4,133,230 A		1/1979	Inaba et al.	82/28 R
4,475,873 A	*	10/1984	Jensen et al.	417/422
5,009,554 A		4/1991	Kameyama et al.	409/231
5,042,348 A		8/1991	Brundage et al.	83/471.3

(Continued)

FOREIGN PATENT DOCUMENTS

DE	34 03 934	*	8/1985

(Continued)

OTHER PUBLICATIONS

Reciprocating saw manufactured by Milwaukee Electric Tool Corporation that includes a magnet hub. The saw was offered for sale as early as Apr. 2000 (see attached statement of relevance and FIGS. 1-3).

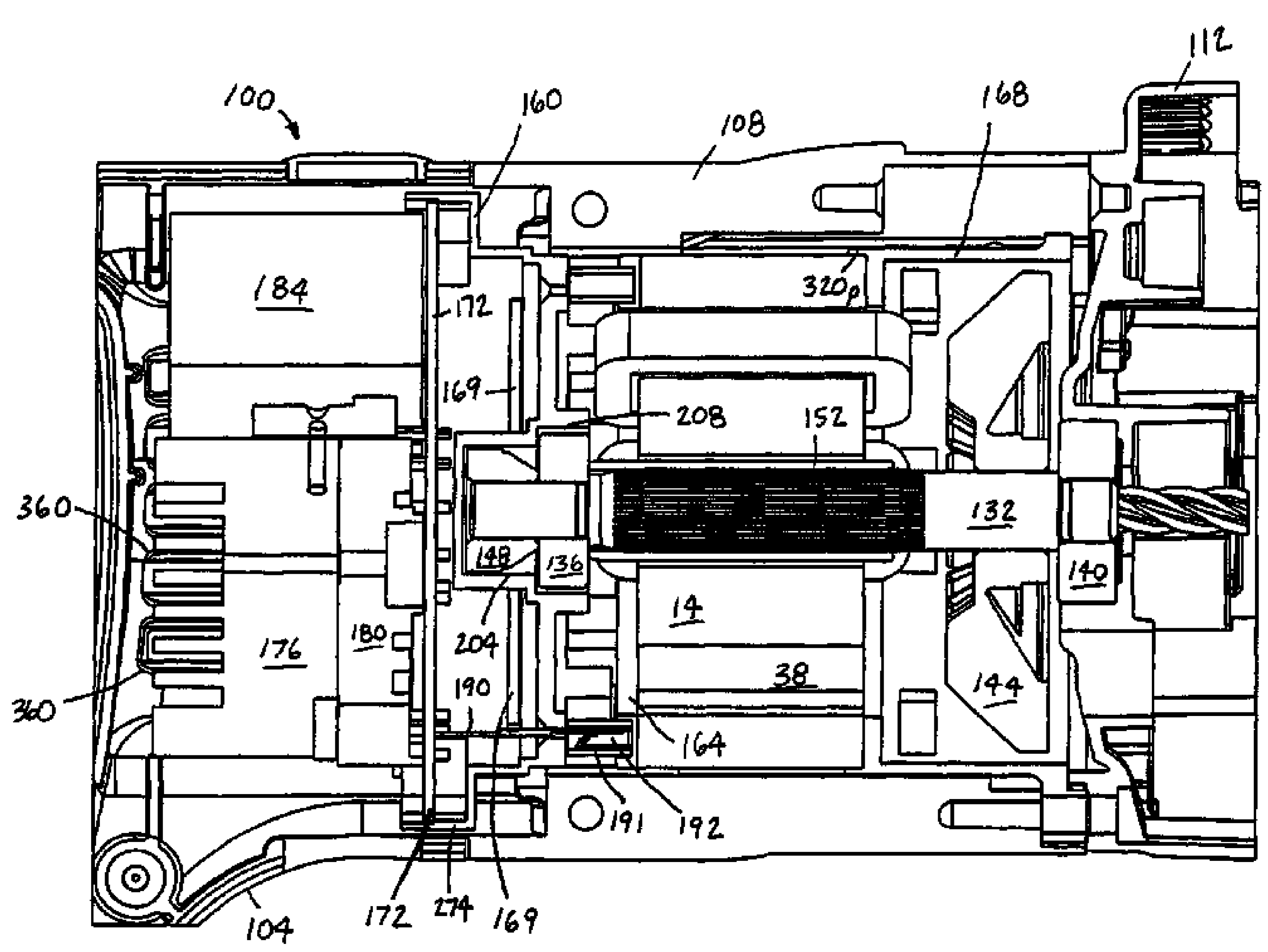
Primary Examiner—Karl I Tamai

(74) *Attorney, Agent, or Firm*—Michael Best & Friedrich LLP

(57) **ABSTRACT**

A method of assembling a power tool, a power tool, a method of assembling an electrical device, and an electrical device includes a switched reluctance motor. The electrical device is preferably a hand-held power tool, however, any type of electrical device that includes a switched reluctance motor may benefit from any number of aspects of the invention. In one independent aspect, the invention provides a construction that reduces tolerance stack-up. In another independent aspect, the invention provides a self-contained electronics package that plugs into a switched reluctance motor to provide control operation of the switched reluctance motor. In another independent aspect, the invention provides enhanced cooling that increases the efficiency of the electrical device using a switched reluctance motor. In another independent aspect, the invention provides an encapsulated magnet that allows for contaminant free motor control over the life of the SR motor. In another independent aspect, the invention provides an apparatus and a method for aligning magnets of a magnet hub with respect to the rotor poles the magnet poles represent.

18 Claims, 40 Drawing Sheets



U.S. PATENT DOCUMENTS

5,119,466	A	6/1992	Suzuki	388/831
5,430,931	A *	7/1995	Fisher et al.	29/596
5,517,746	A	5/1996	Cox et al.	29/560
5,532,533	A *	7/1996	Mizutani	310/68 B
5,562,135	A	10/1996	Beth et al.	144/1.1
5,625,239	A	4/1997	Persson et al.	310/68 B
5,724,875	A	3/1998	Meredith et al.	83/937
5,765,273	A	6/1998	Mora et al.	29/550
5,770,902	A	6/1998	Batten et al.	310/71
5,771,949	A	6/1998	Welsh et al.	144/130
5,825,107	A *	10/1998	Johnson et al.	310/64
5,864,477	A	1/1999	Webster	363/132
5,936,373	A	8/1999	Li et al.	318/701
5,957,021	A	9/1999	Meredith et al.	83/397
5,960,531	A	10/1999	Mora et al.	29/560
5,967,205	A	10/1999	Welsh et al.	144/117.1
6,011,331	A	1/2000	Gierer et al.	310/58
6,028,386	A *	2/2000	Kech et al.	310/194
6,076,573	A	6/2000	Welsh et al.	144/117.1
6,123,158	A	9/2000	Steffen	173/217
6,177,740	B1 *	1/2001	Burns	310/68 R
6,193,473	B1	2/2001	Mruk et al.	417/350
6,262,510	B1	7/2001	Lungu	310/254
6,267,038	B1 *	7/2001	O'Banion et al.	83/781
6,276,038	B1	8/2001	Boochakorn	29/281.5
6,320,286	B1	11/2001	Ramarathnam	310/50
6,538,403	B2	3/2003	Gorti et al.	318/254
6,570,284	B1 *	5/2003	Agnes et al.	310/89
7,064,462	B2 *	6/2006	Hempe et al.	310/50
2001/0032534	A1	10/2001	Ceroll et al.	83/473
2001/0033742	A1	10/2001	Weaver et al.	388/800
2001/0042630	A1	11/2001	Kristin et al.	173/1
2001/0043806	A1	11/2001	Gorti et al.	388/800
2001/0052416	A1	12/2001	Wissmach et al.	174/4
2002/0047414	A1	4/2002	Latimer	310/112
2003/0163924	A1	9/2003	Hempe et al.	30/388

FOREIGN PATENT DOCUMENTS

DE	19527981		2/1997
DE	19816684		12/1999
EP	0 064 105		11/1982
EP	0096251	*	12/1983
EP	0709155		5/1996
EP	0934789	A2	8/1999
GB	2295730		6/1996
GB	2319908		6/1998
GB	2362120		11/2001
WO	WO 00/74204	A2	12/2000
WO	WO 00/74204	A3	12/2000
WO	WO 03/050931	A1	6/2003

* cited by examiner

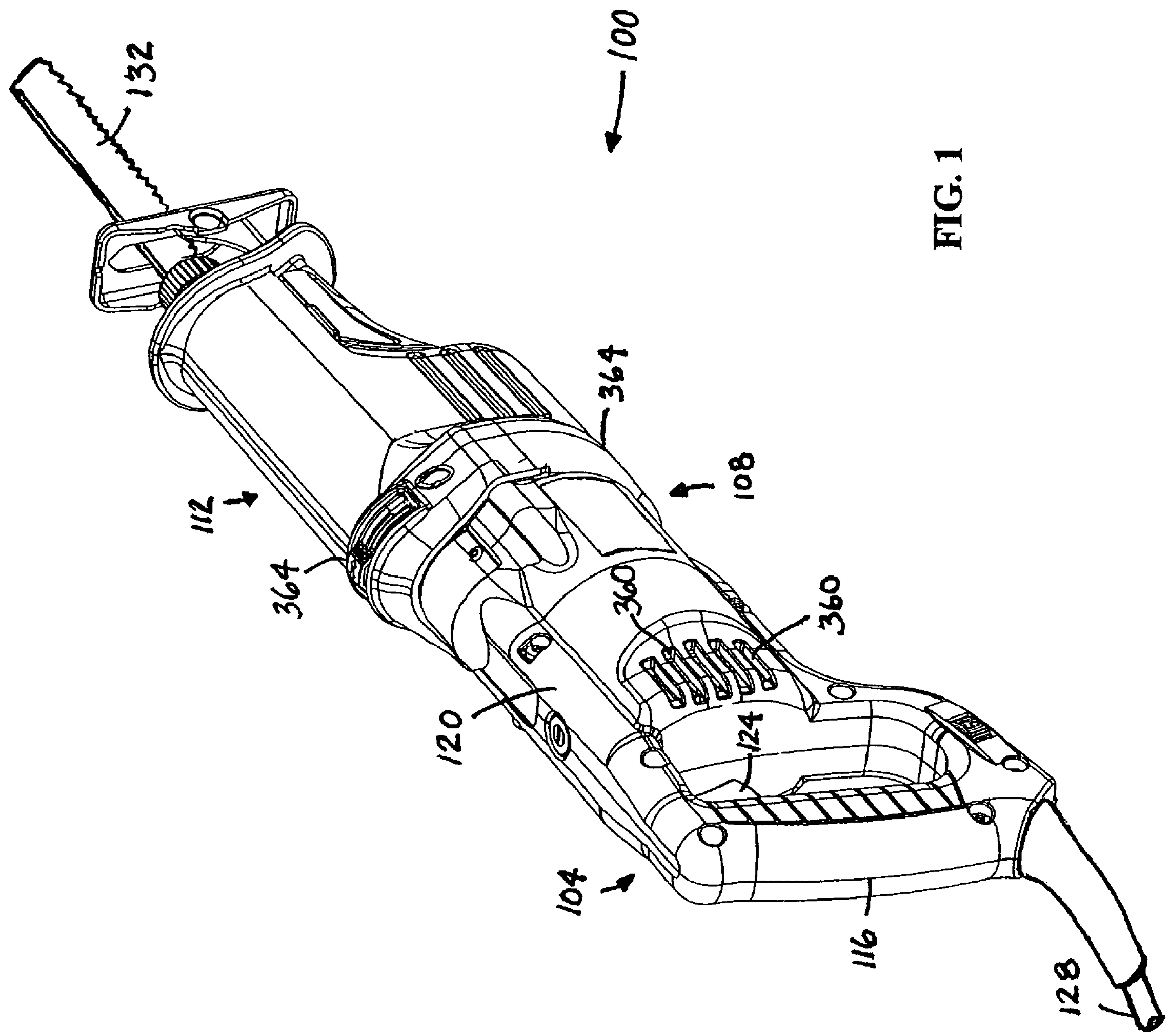


FIG. 1

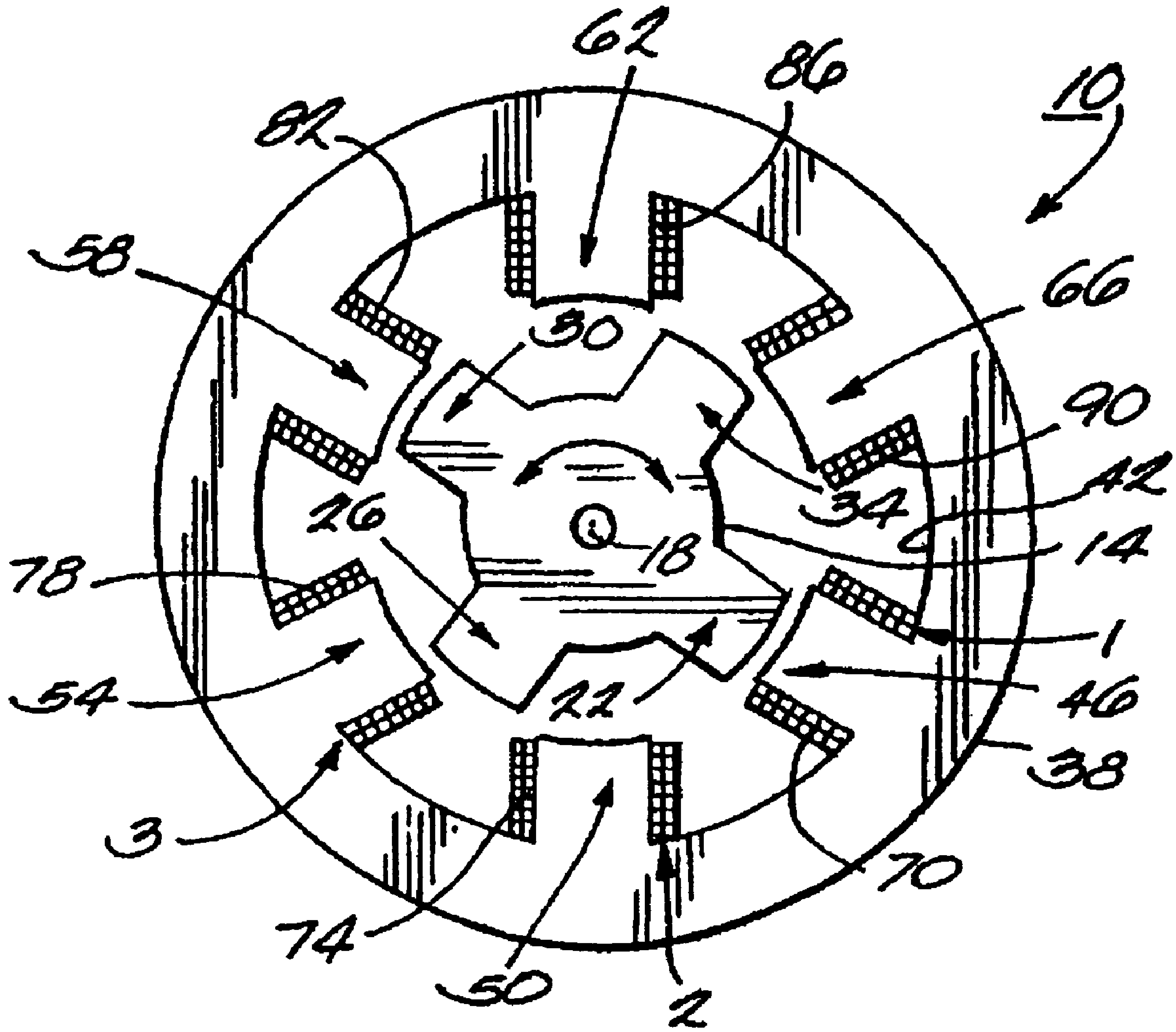


FIG. 2

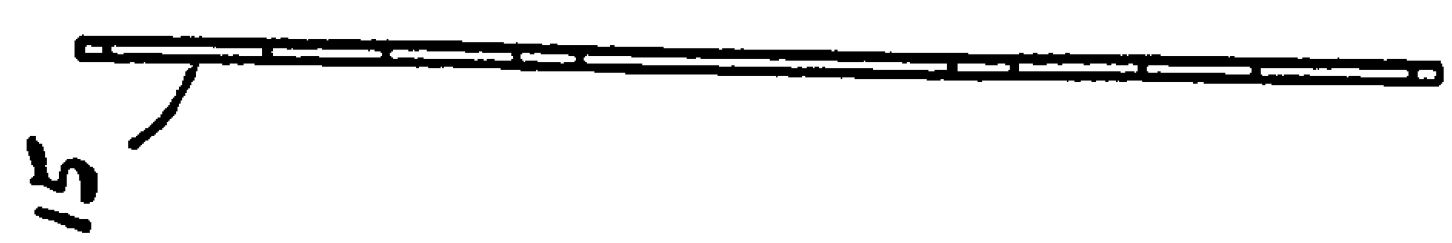


FIG. 3C

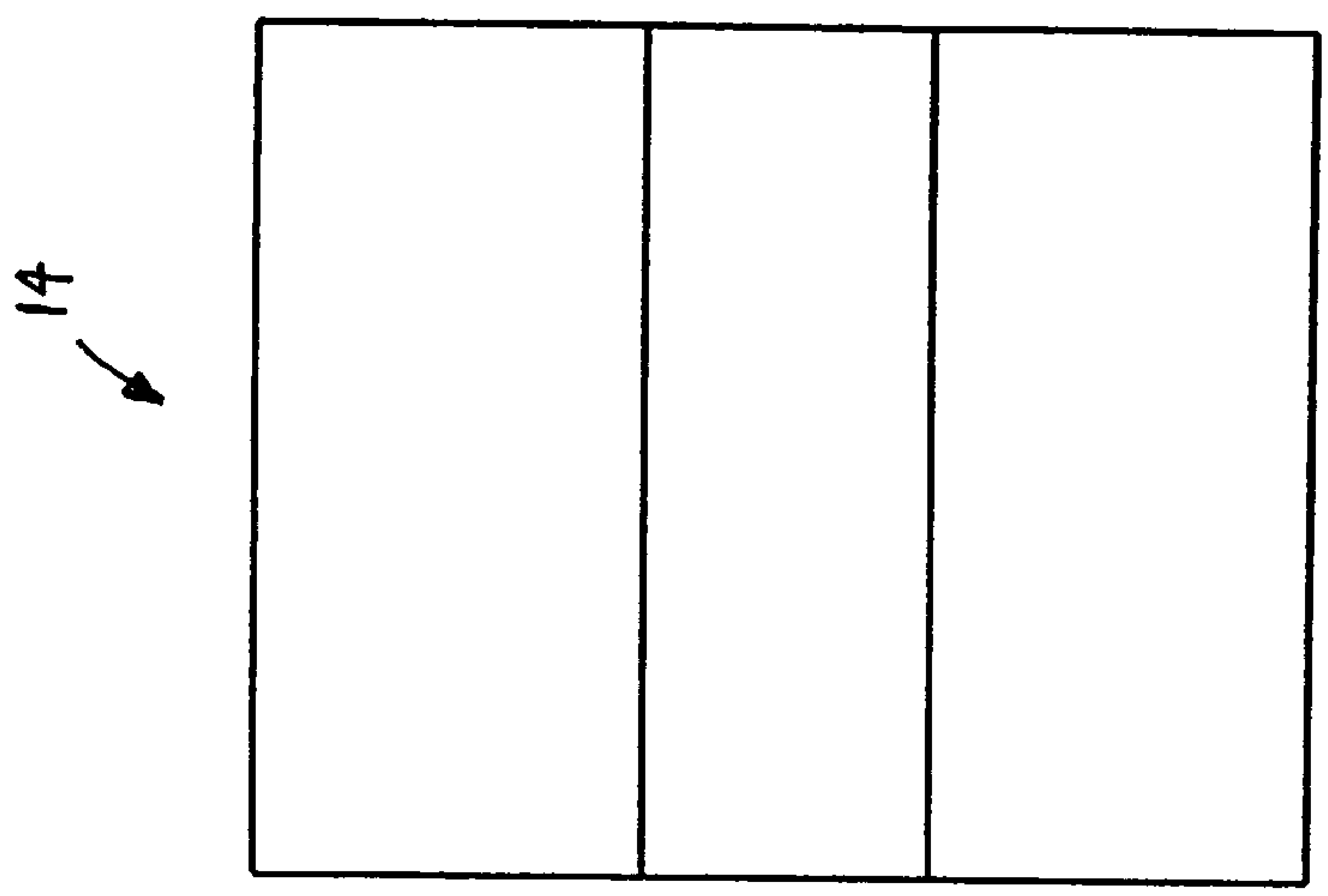


FIG. 3B

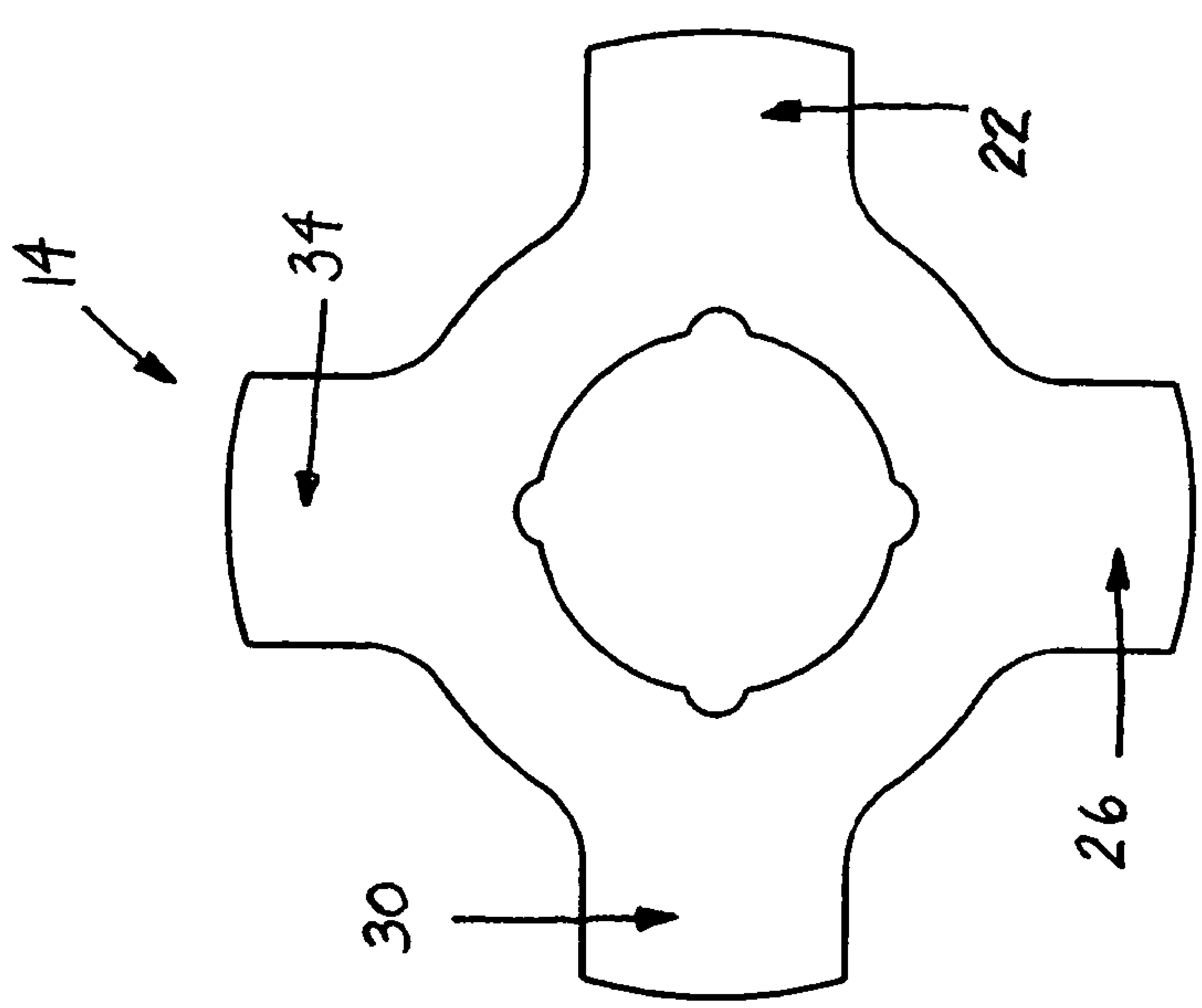


FIG. 3A

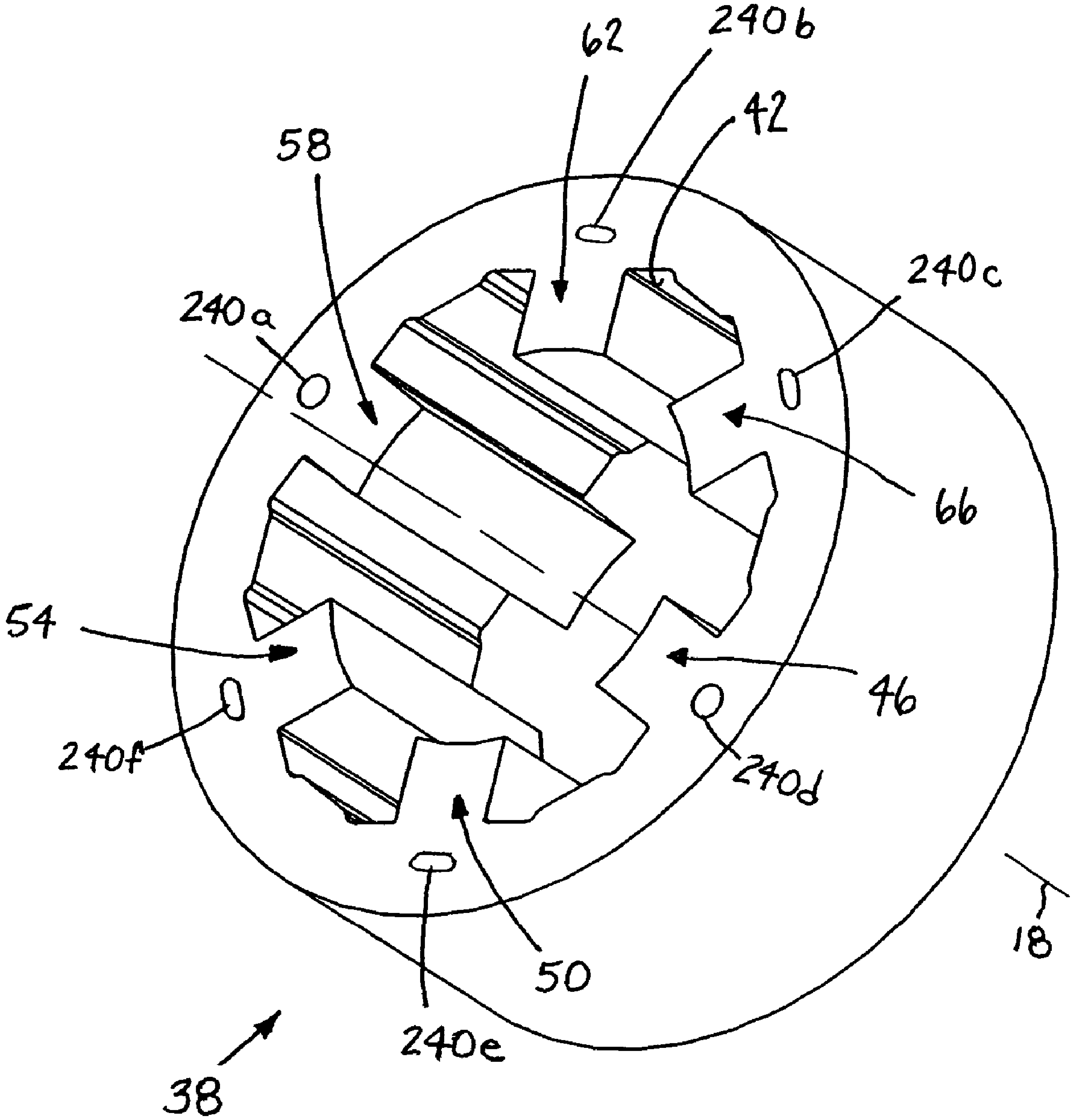


FIG. 4

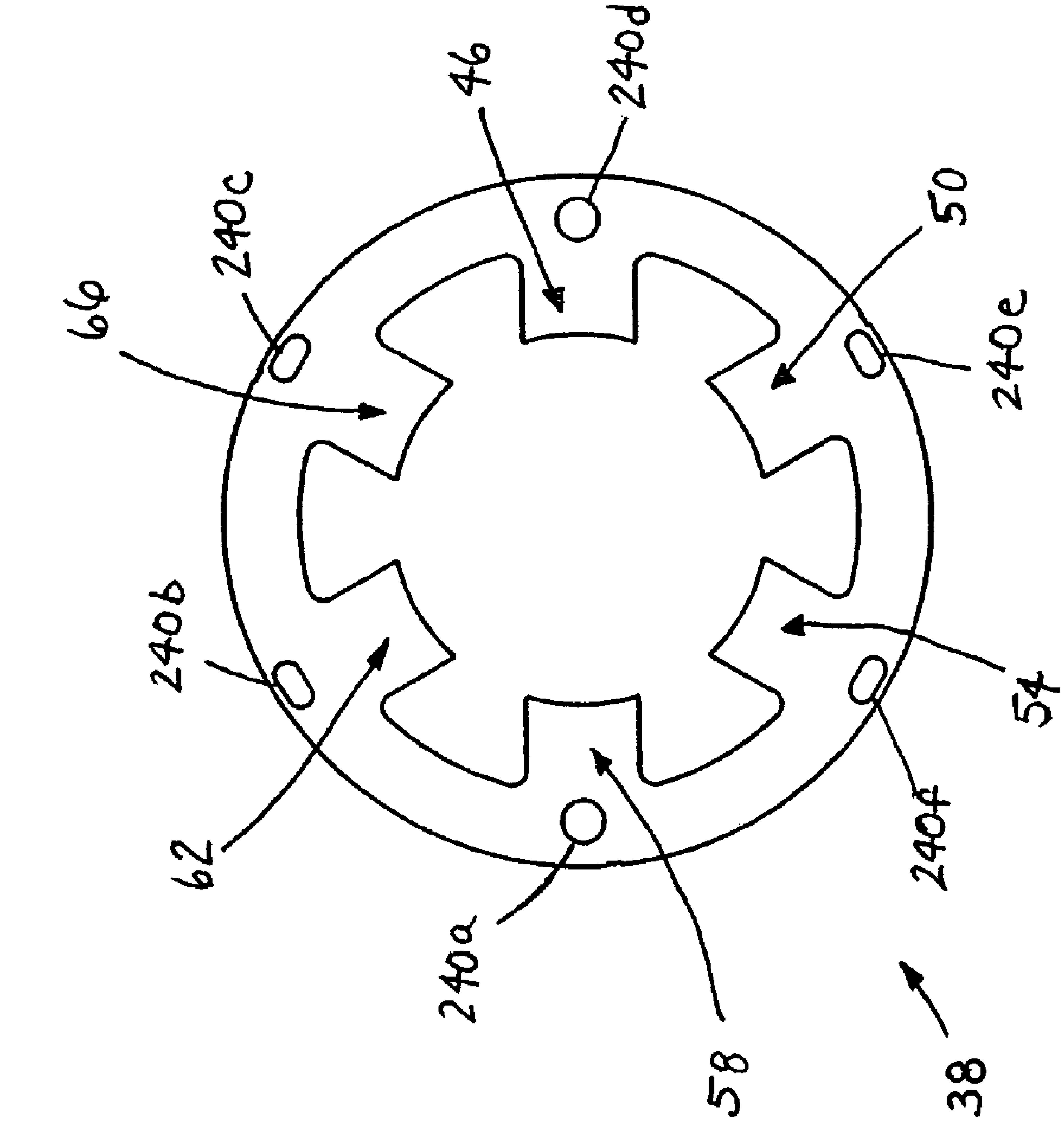


FIG. 5A

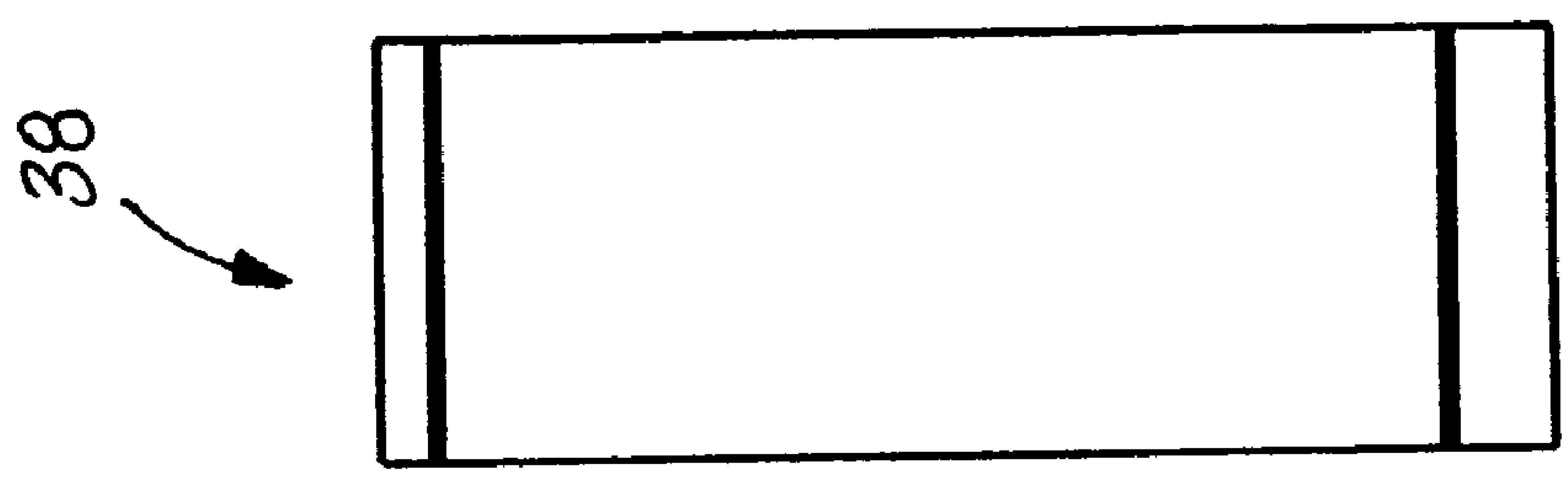


FIG. 5B

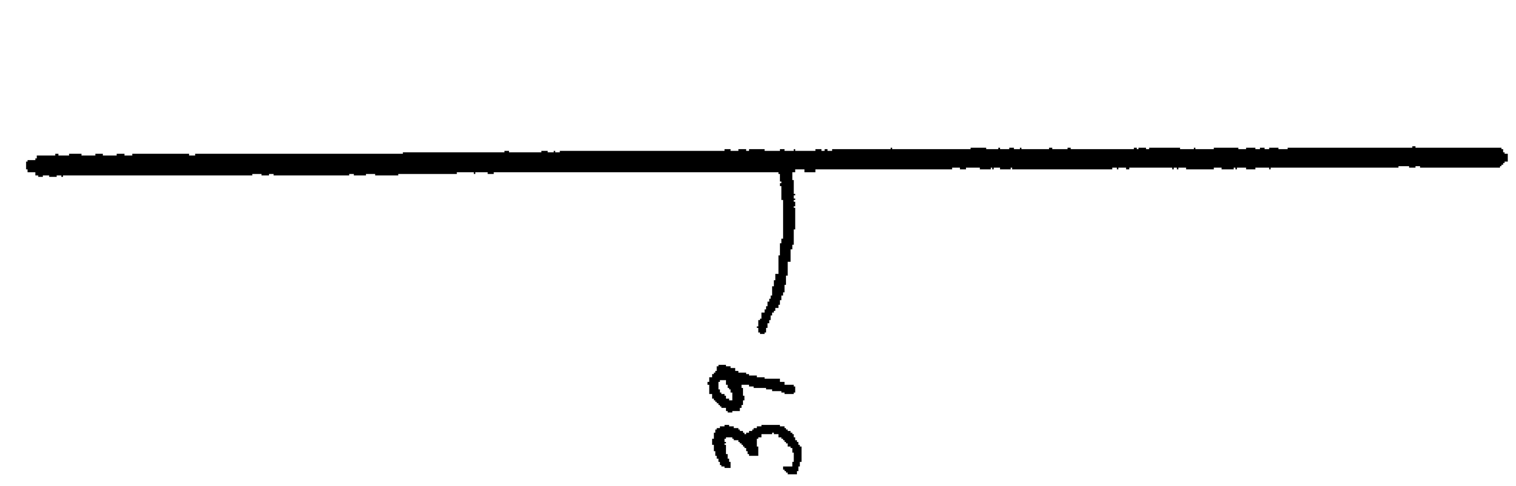


FIG. 5C

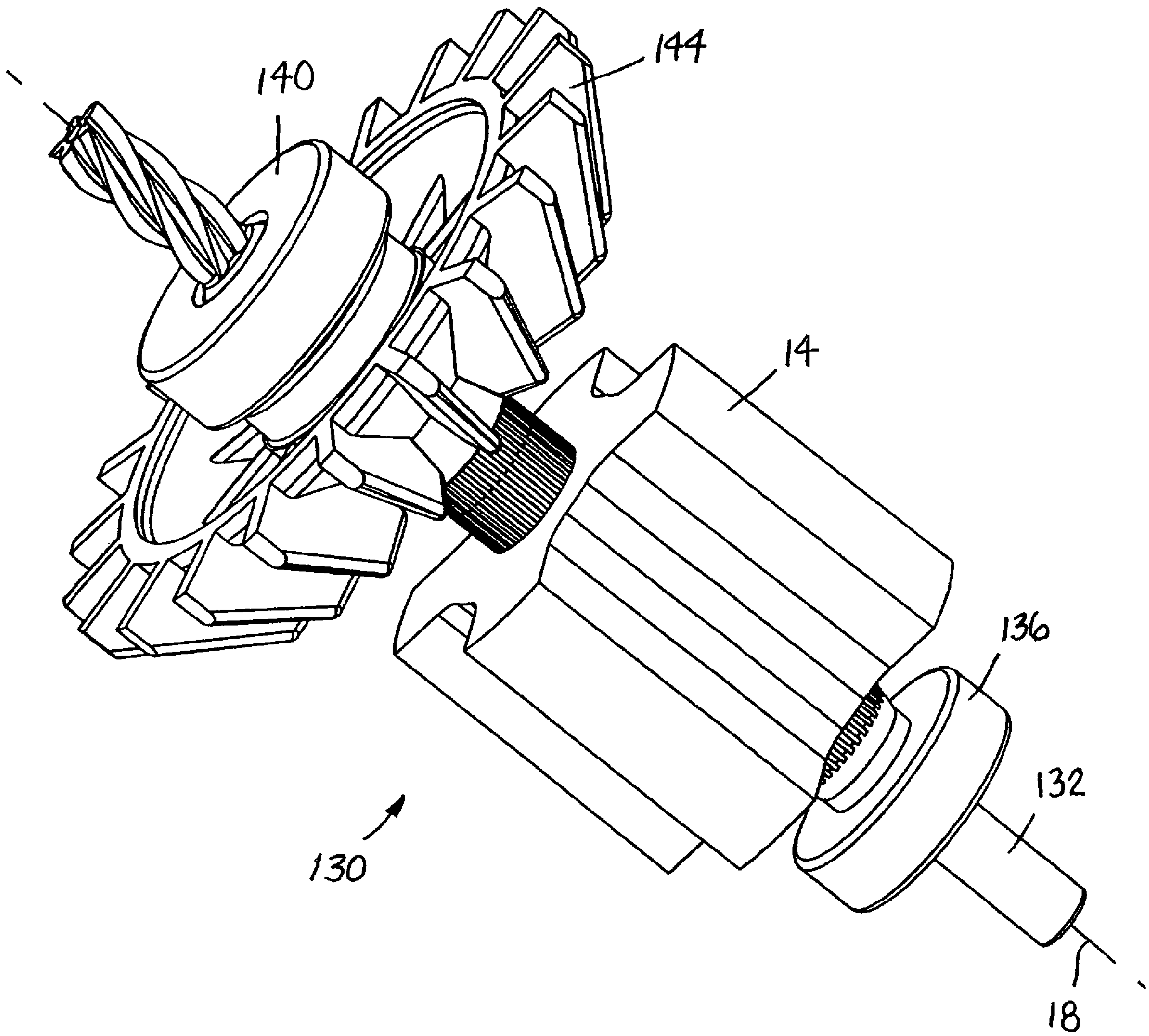


FIG. 6

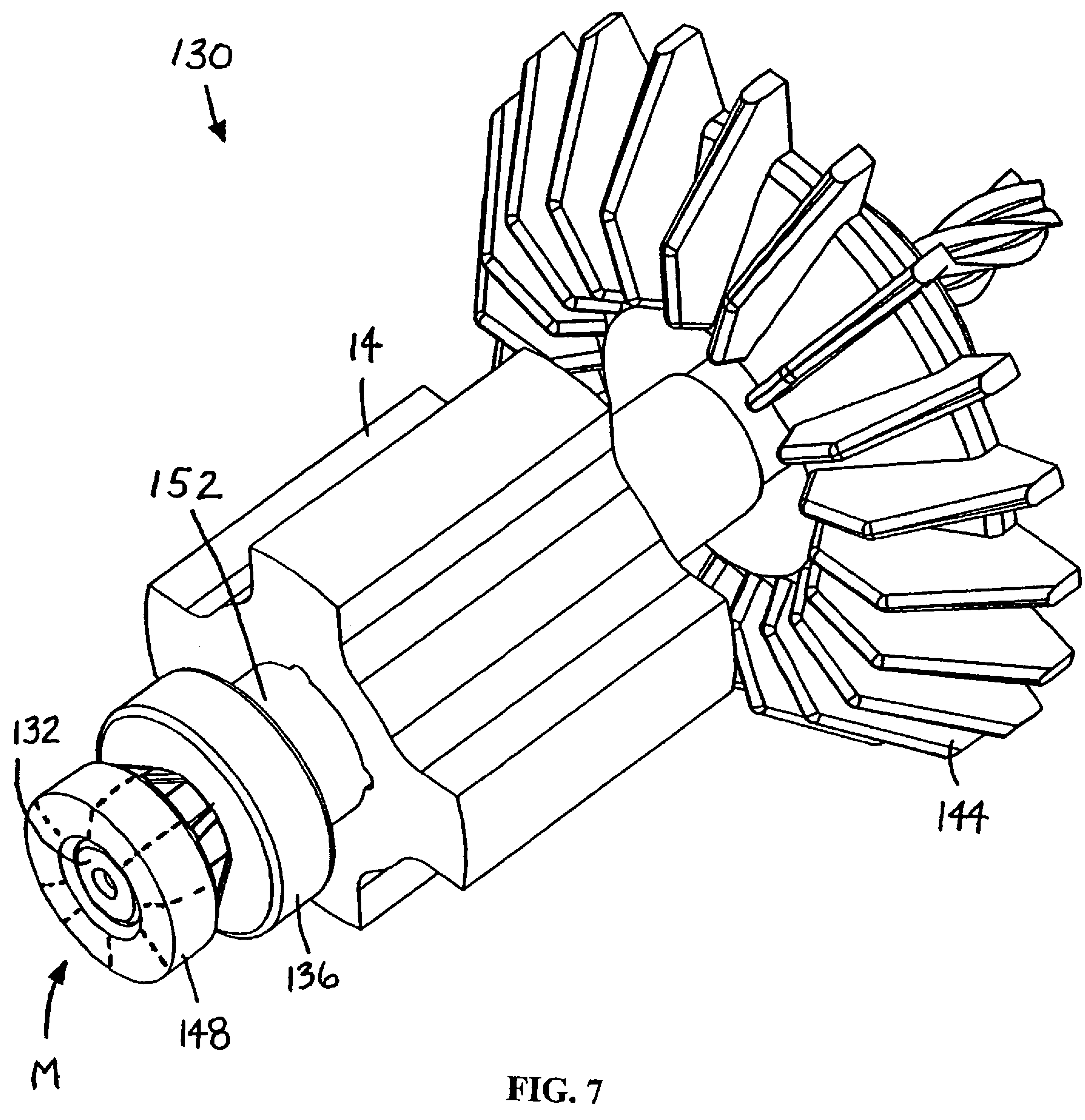


FIG. 7

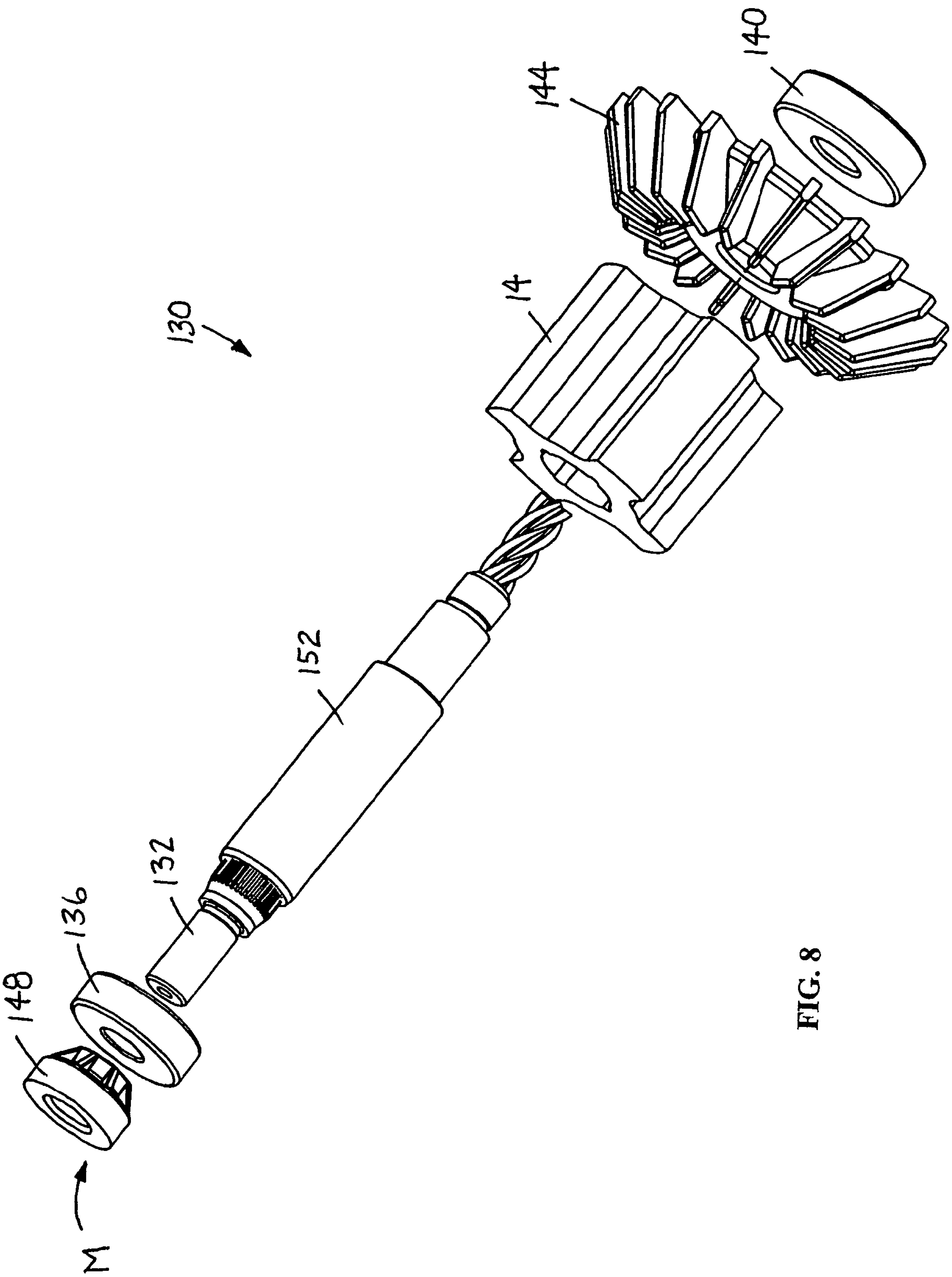


FIG. 8

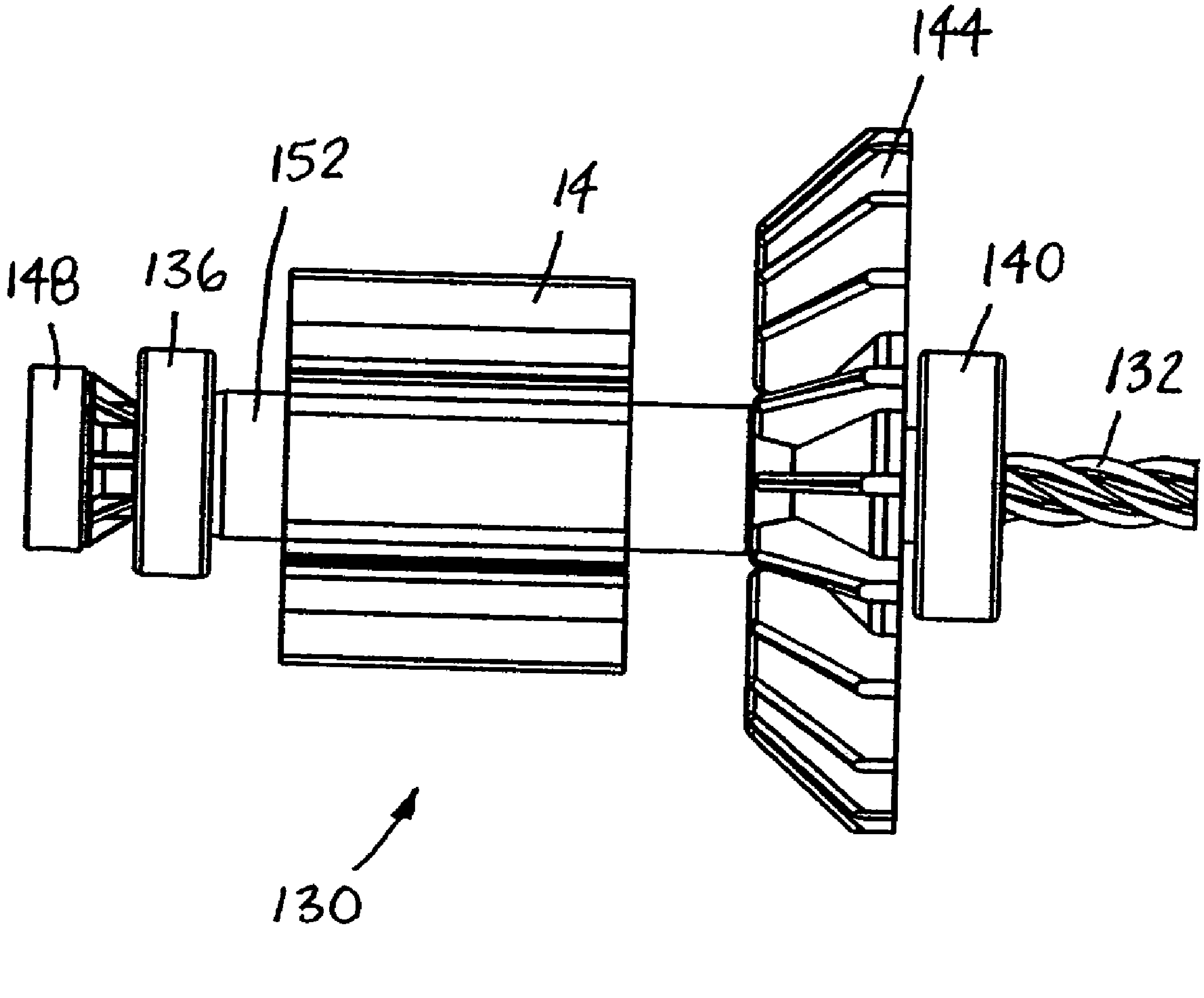


FIG. 9

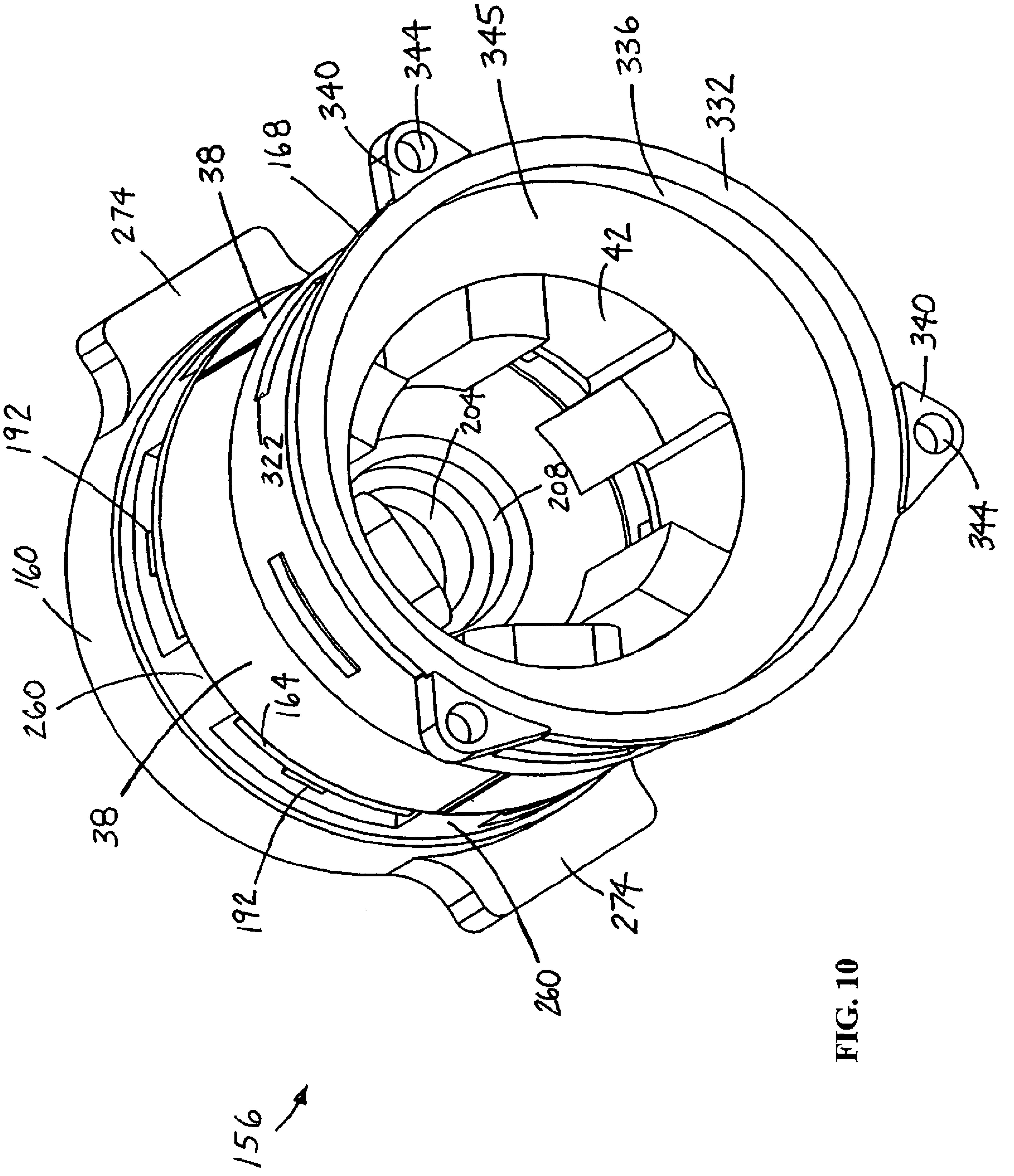
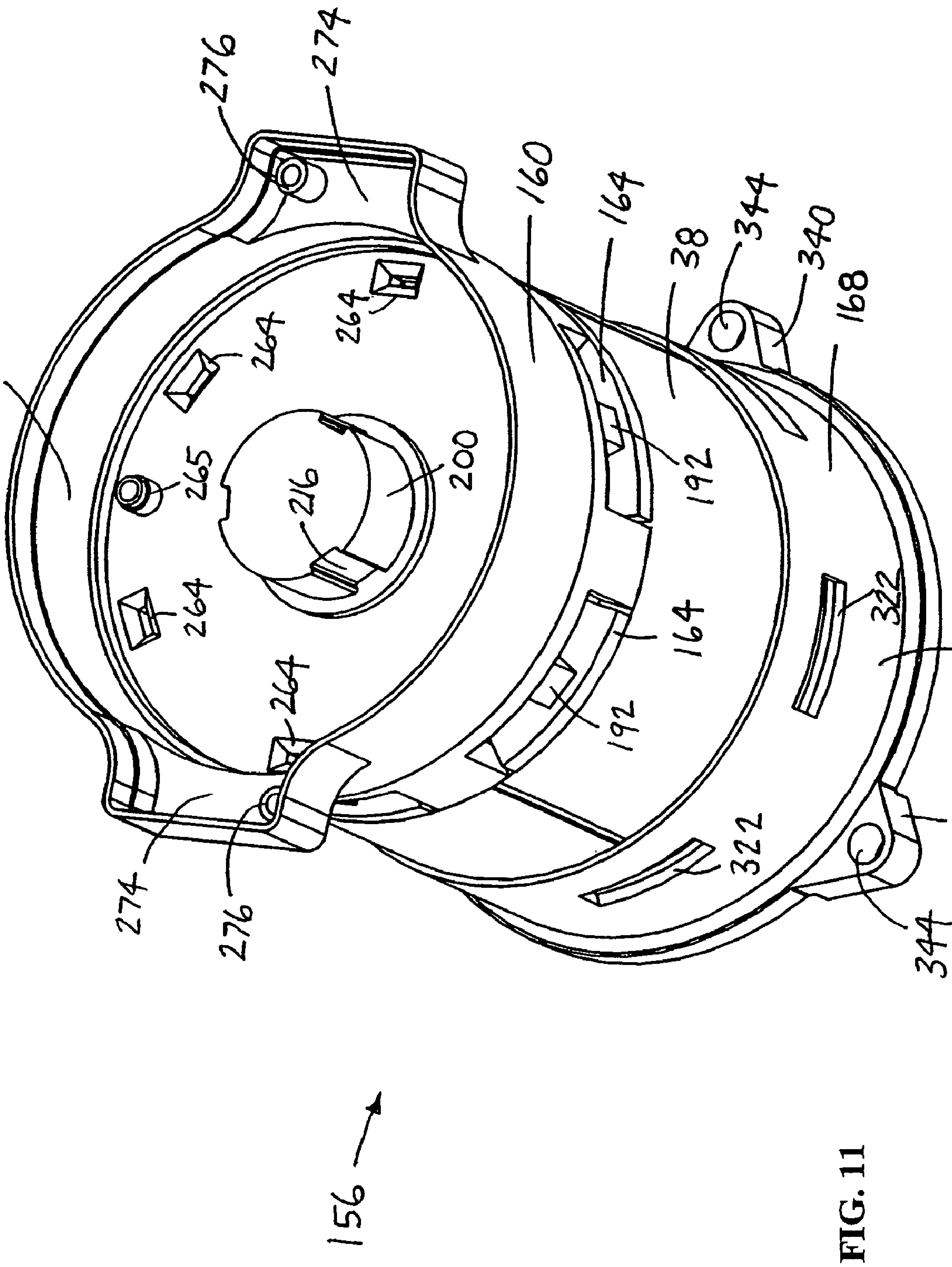

274
38
168
340
344
345
336
332
42
340
344
192
322
204
208
160
260
164
38
192
274
260
156

FIG. 10



272
276
274
160
164
38
344
340
168
264
265
200
216
192
322
320
156

FIG. 11

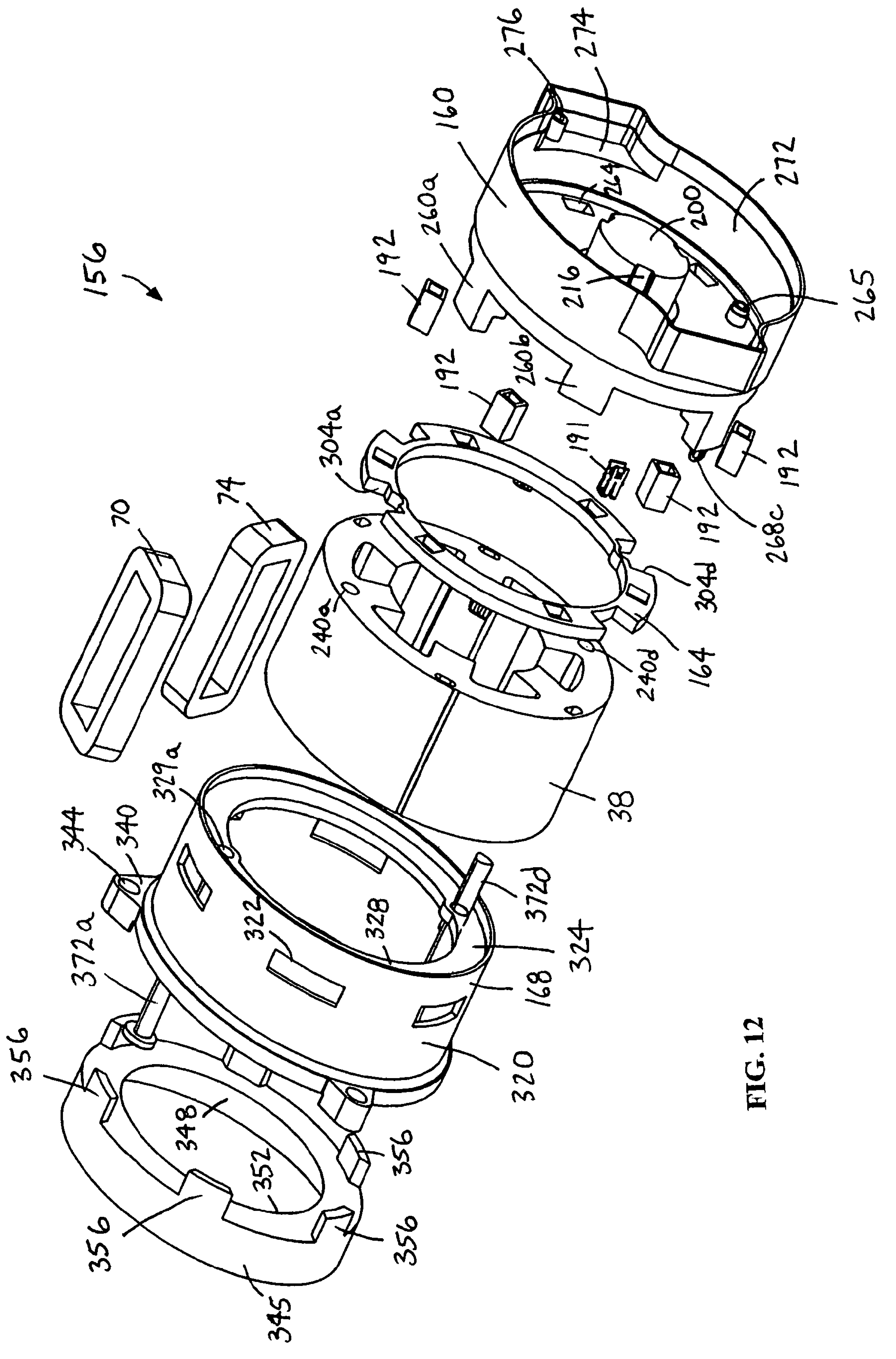

156
276
274
160
260a
192
264
200
272
216
265
260b
192
191
192
192
192
268c
304a
304d
74
70
240a
240d
164
38
329a
344
340
372d
322
328
324
372a
168
320
356
348
352
356
356
356
345

FIG. 12

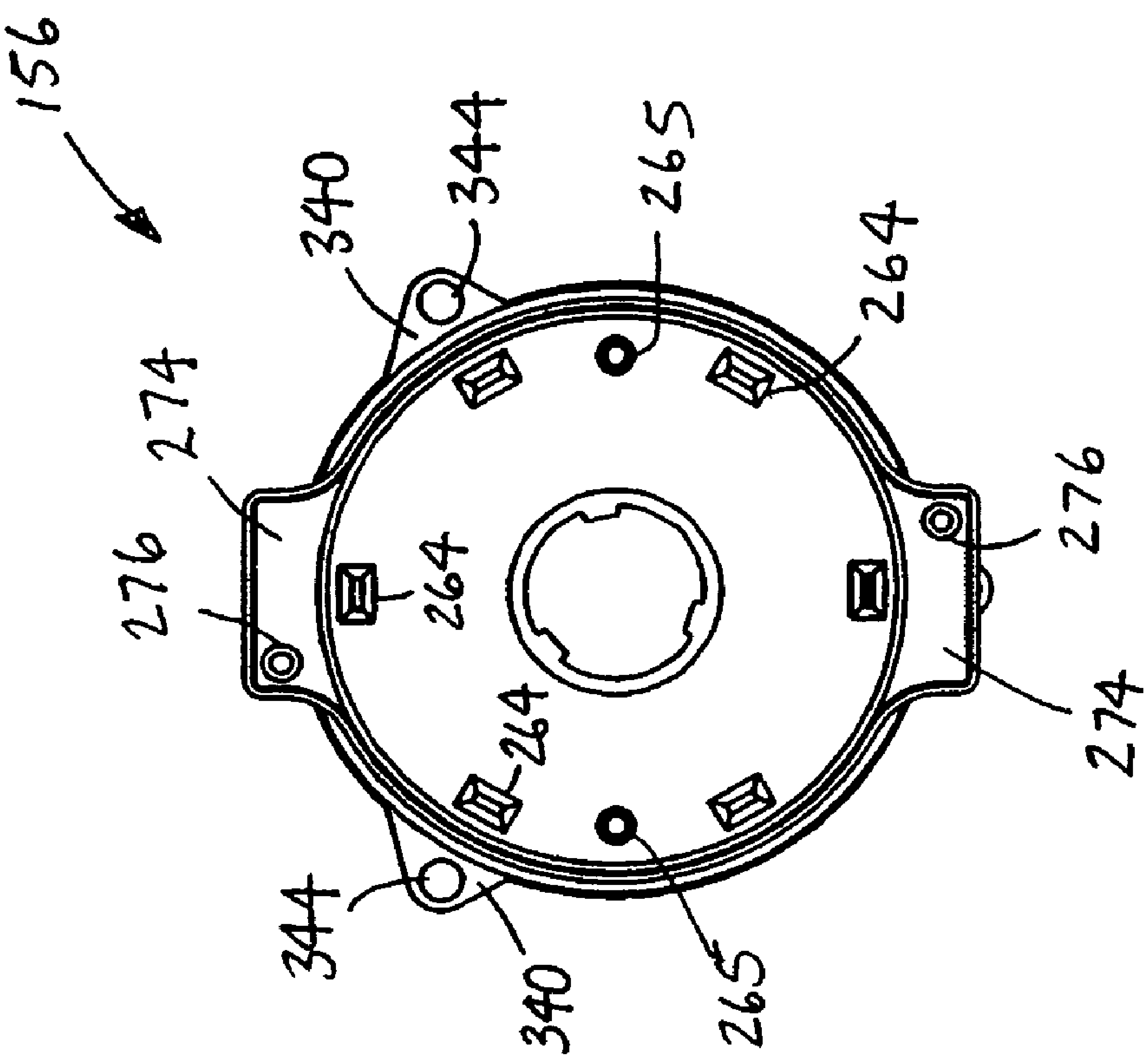


FIG. 13B

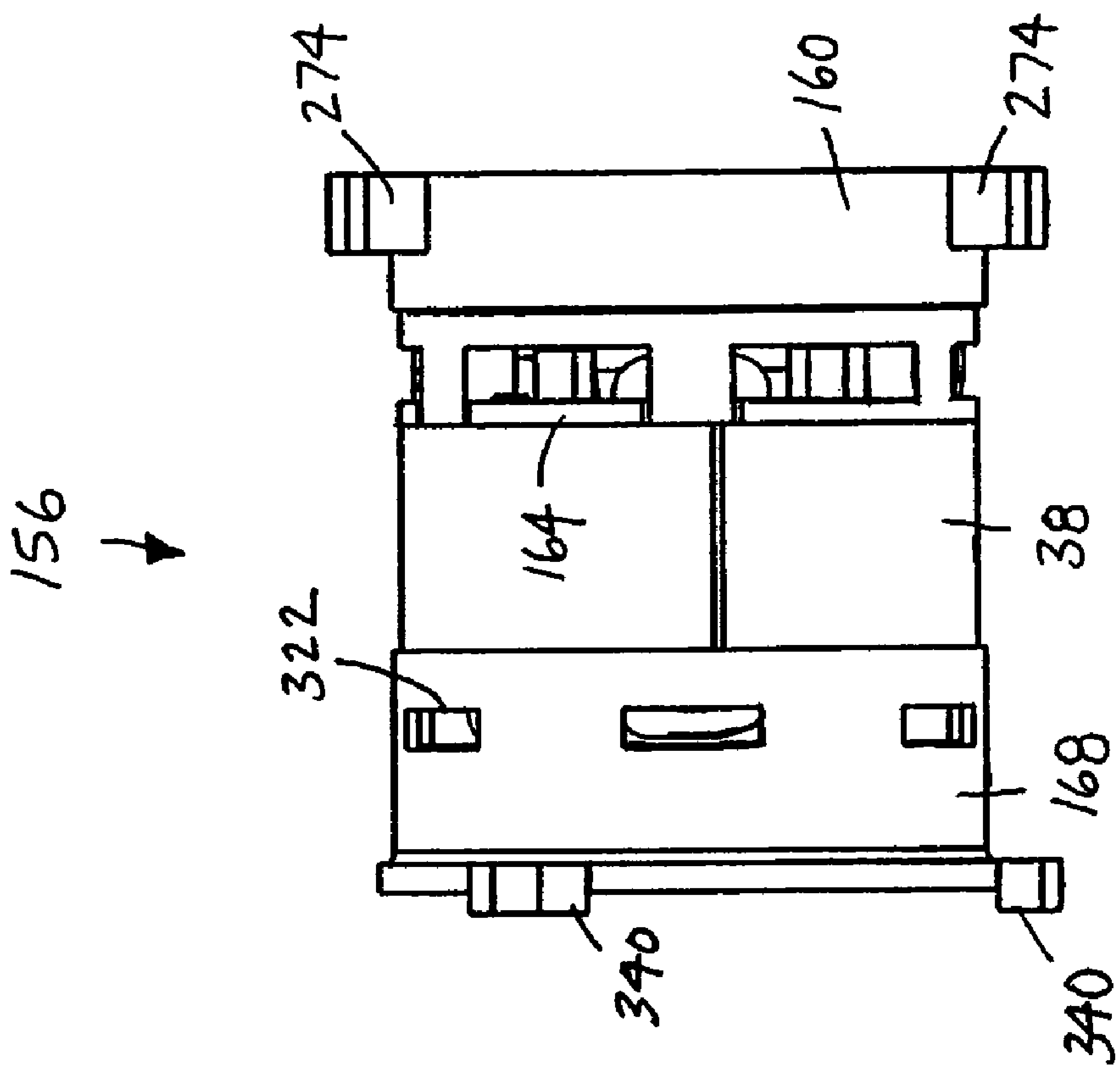


FIG. 13A

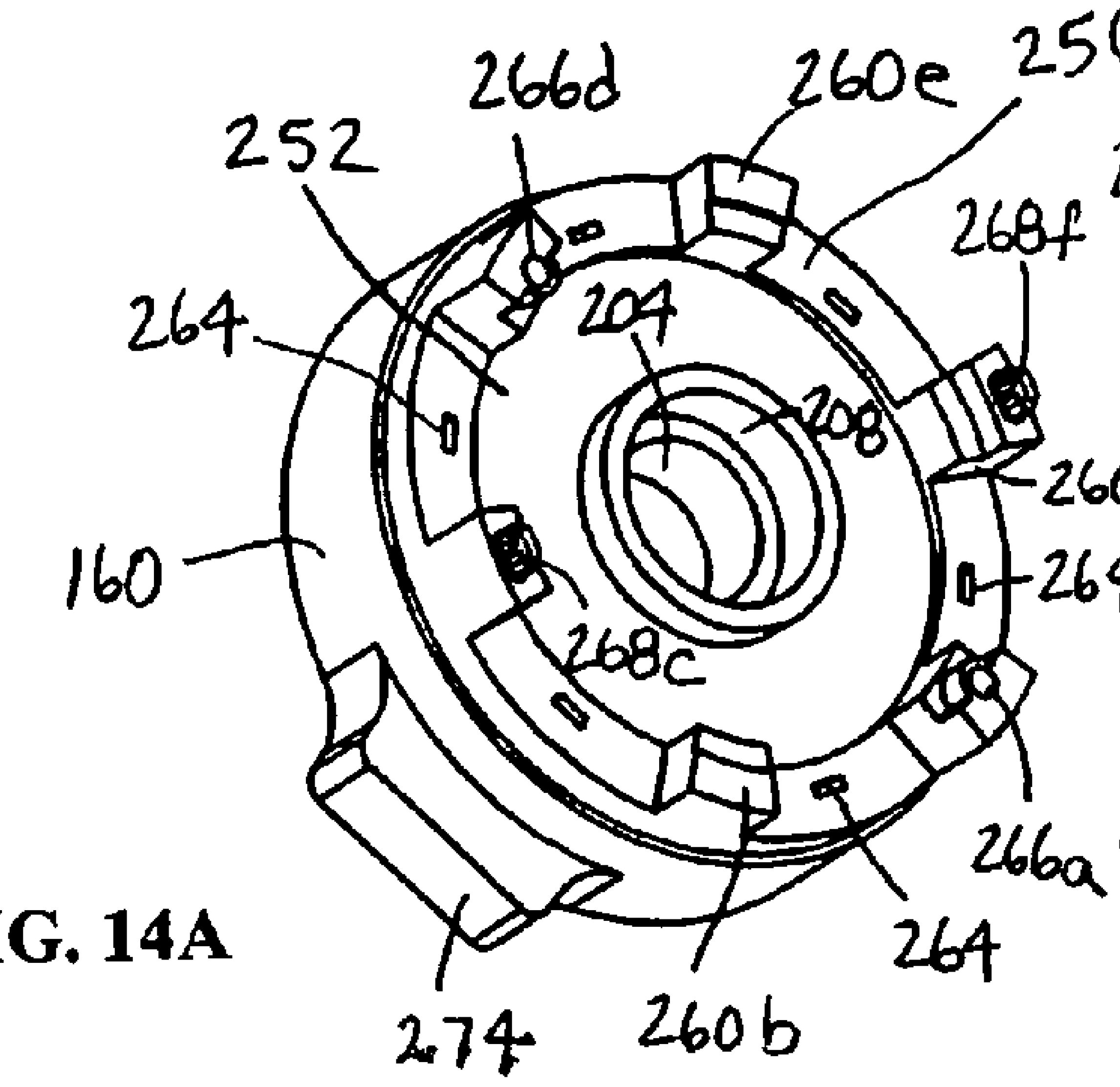


FIG. 14A

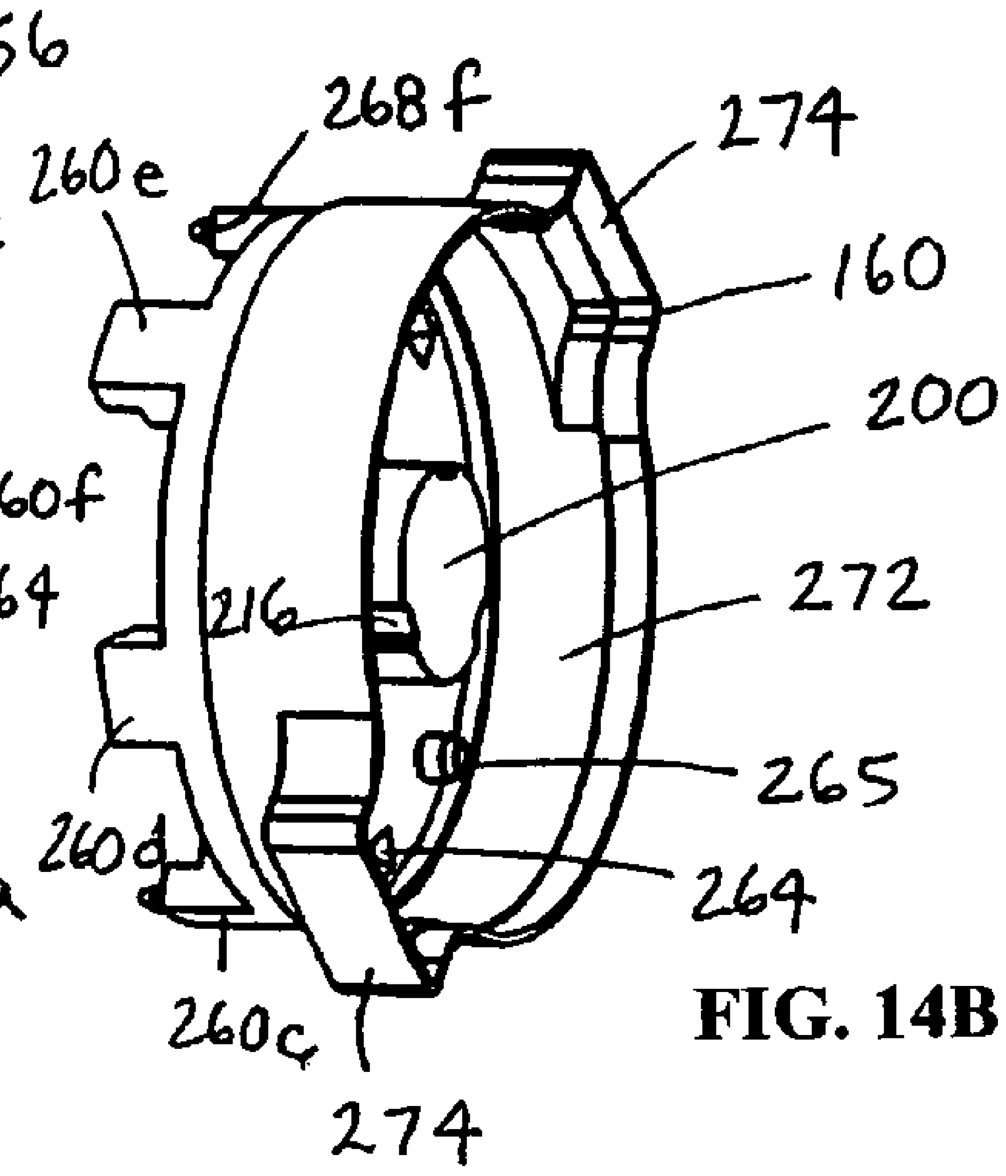


FIG. 14B

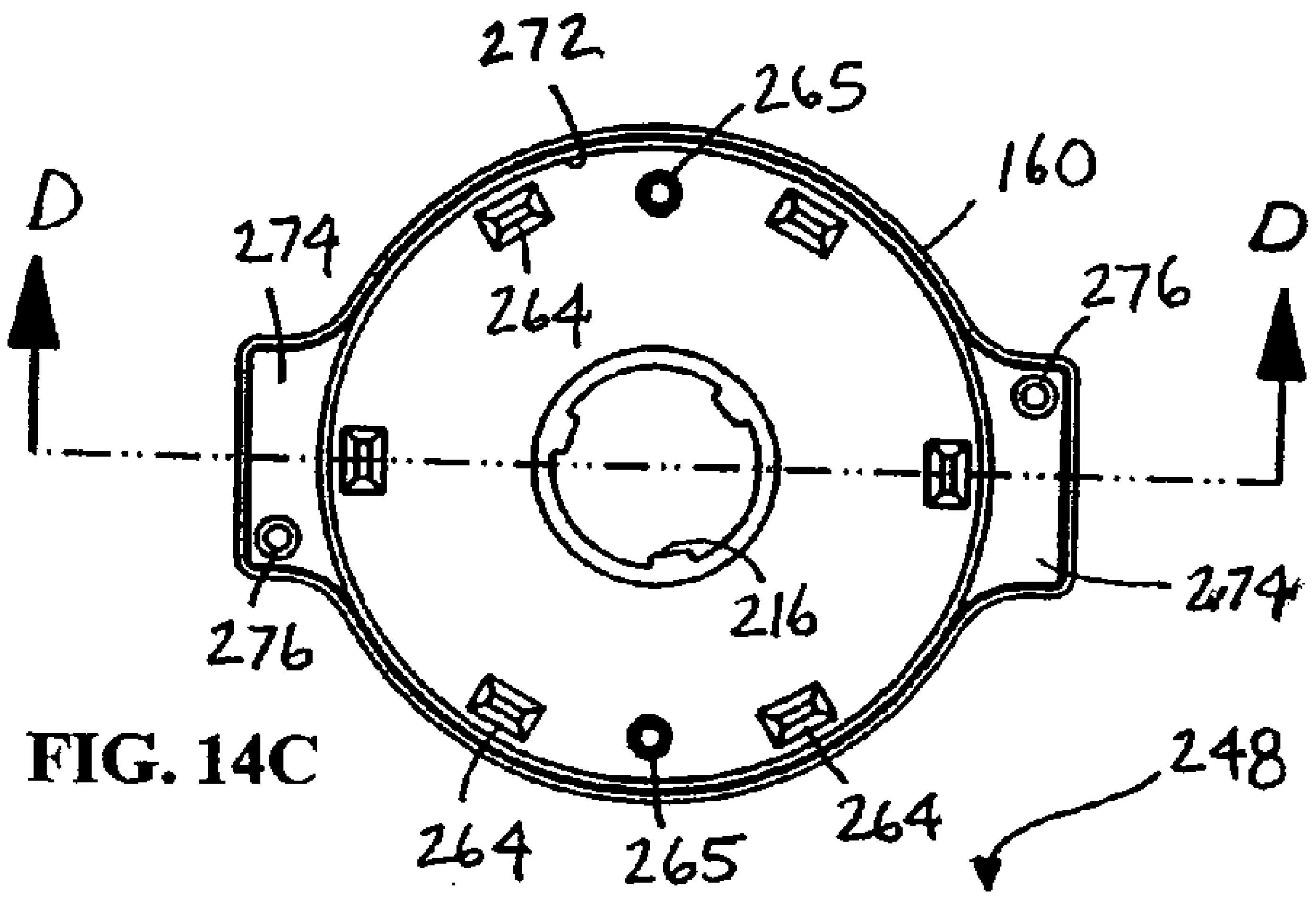


FIG. 14C

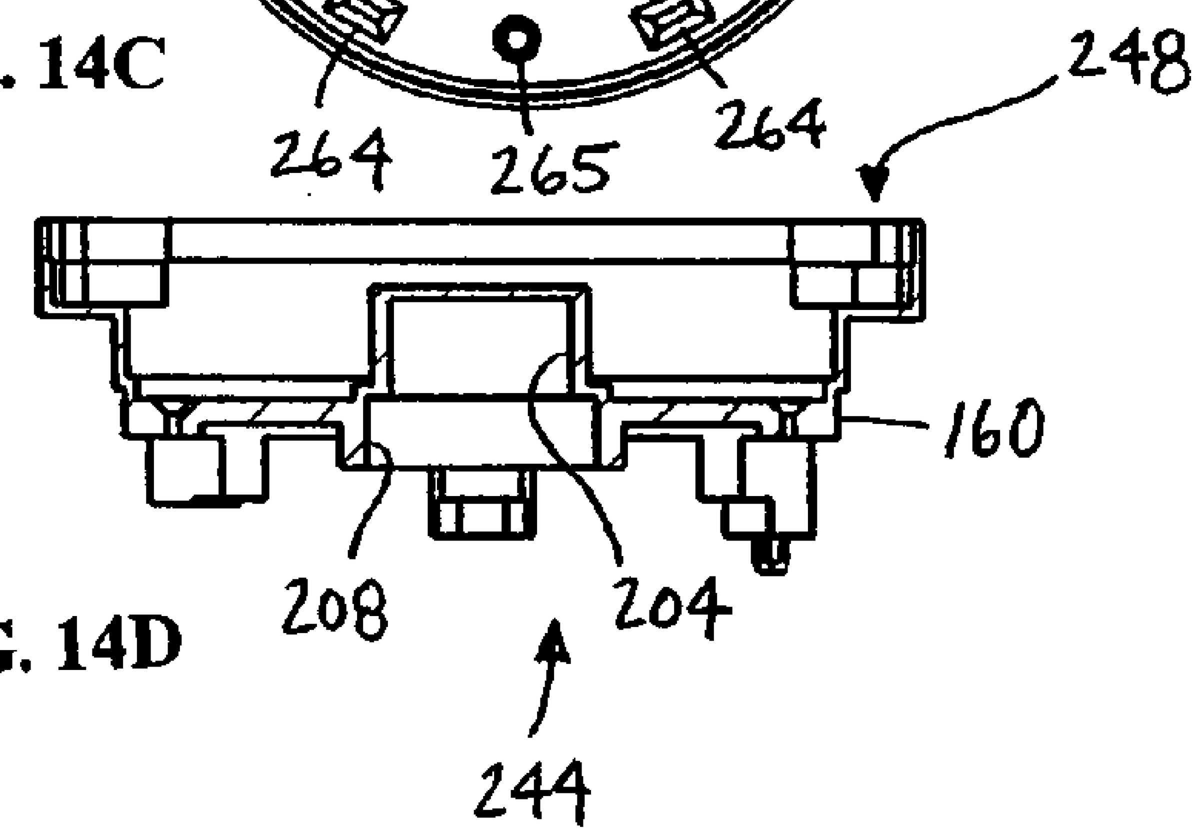


FIG. 14D

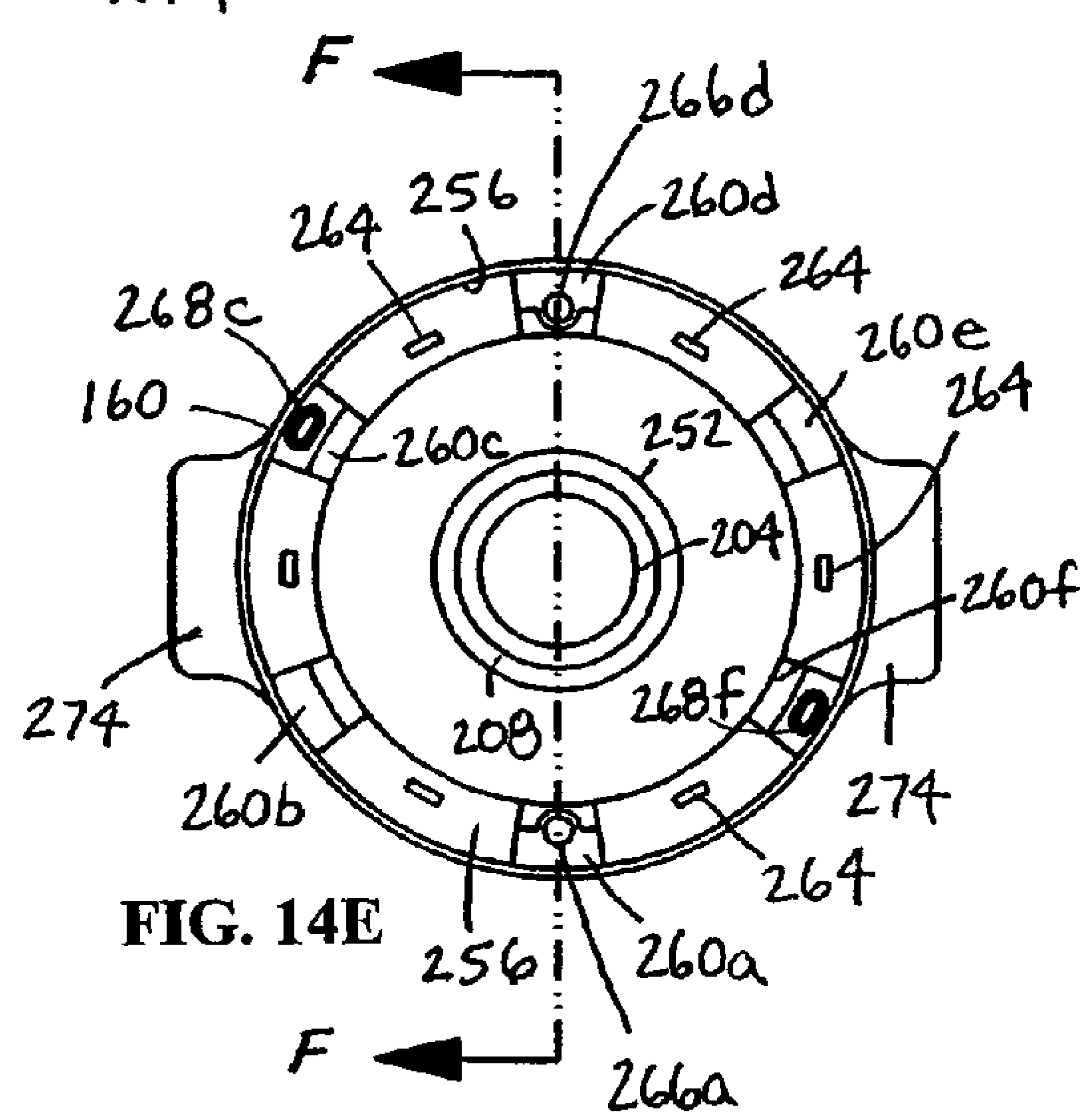


FIG. 14E

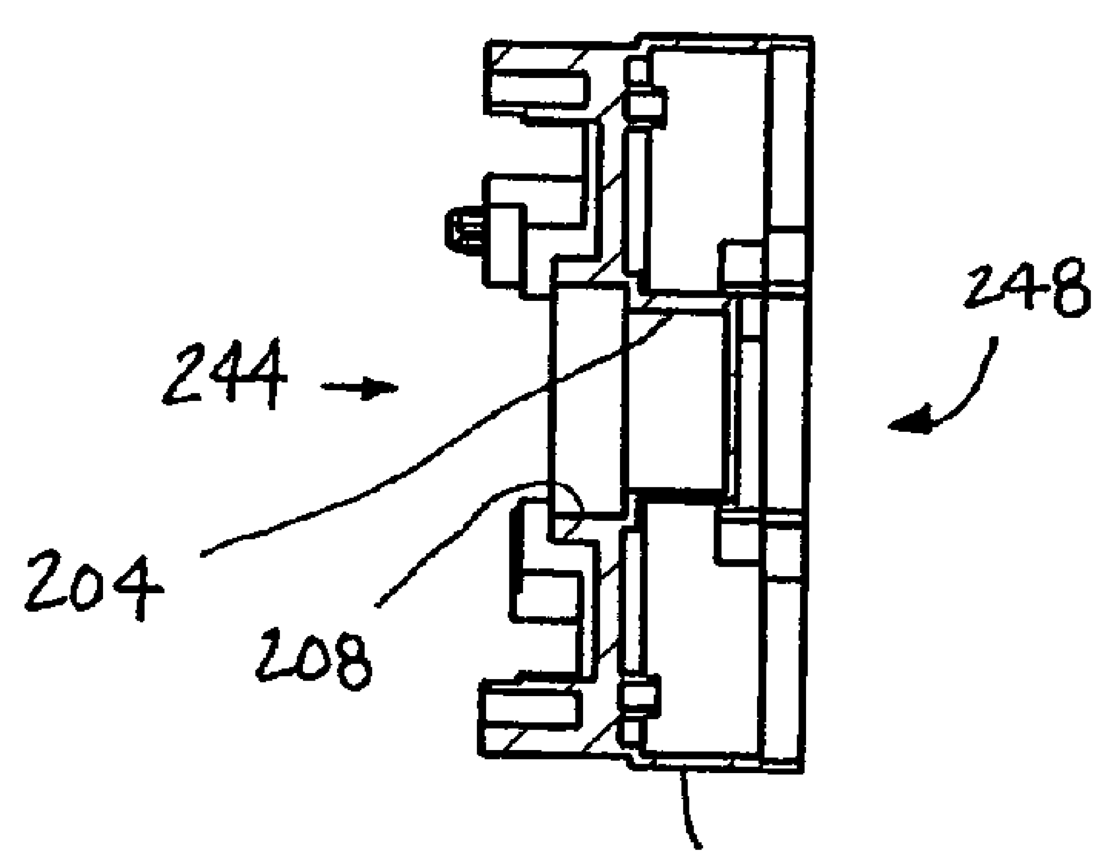
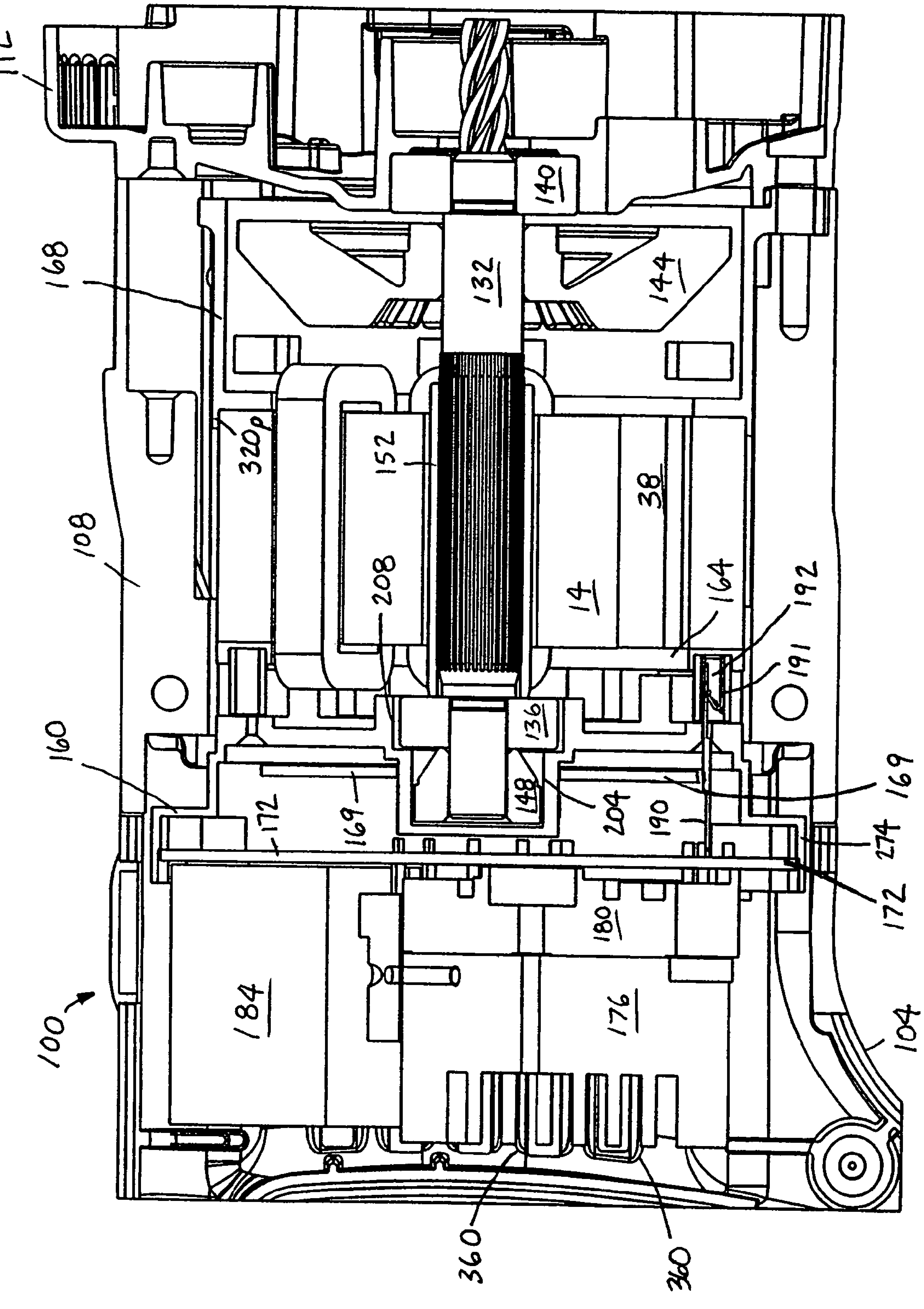


FIG. 14F

FIG. 15


112
168
108
320p
152
208
14
38
164
192
191
140
132
144
136
148
204
160
172
169
190
169
274
172
180
184
176
100
104
360
360

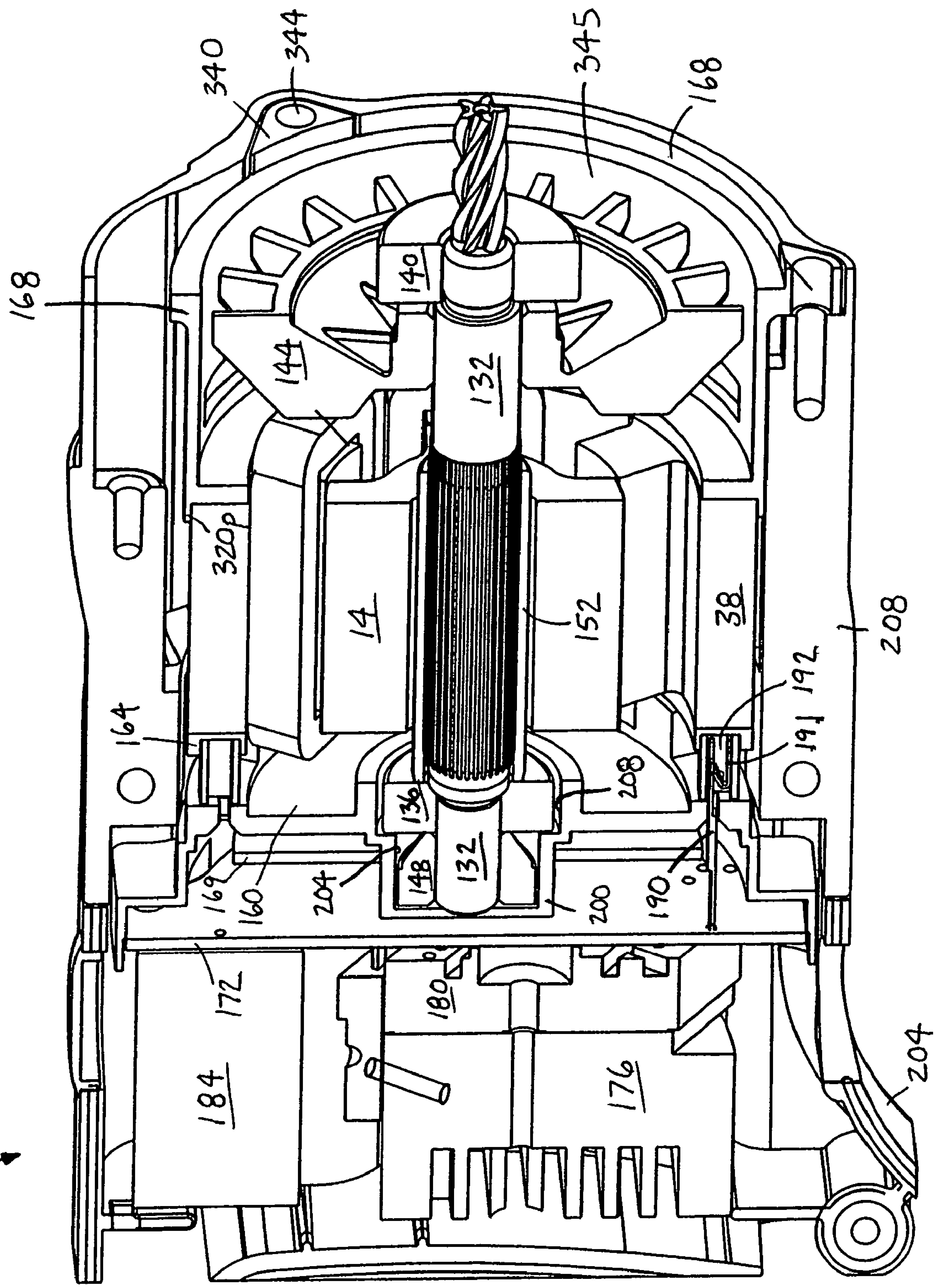

100
340
344
345
168
168
140
144
132
320p
14
152
38
208
164
192
191
208
136
132
148
204
169
160
200
190
172
180
184
176
204

FIG. 16

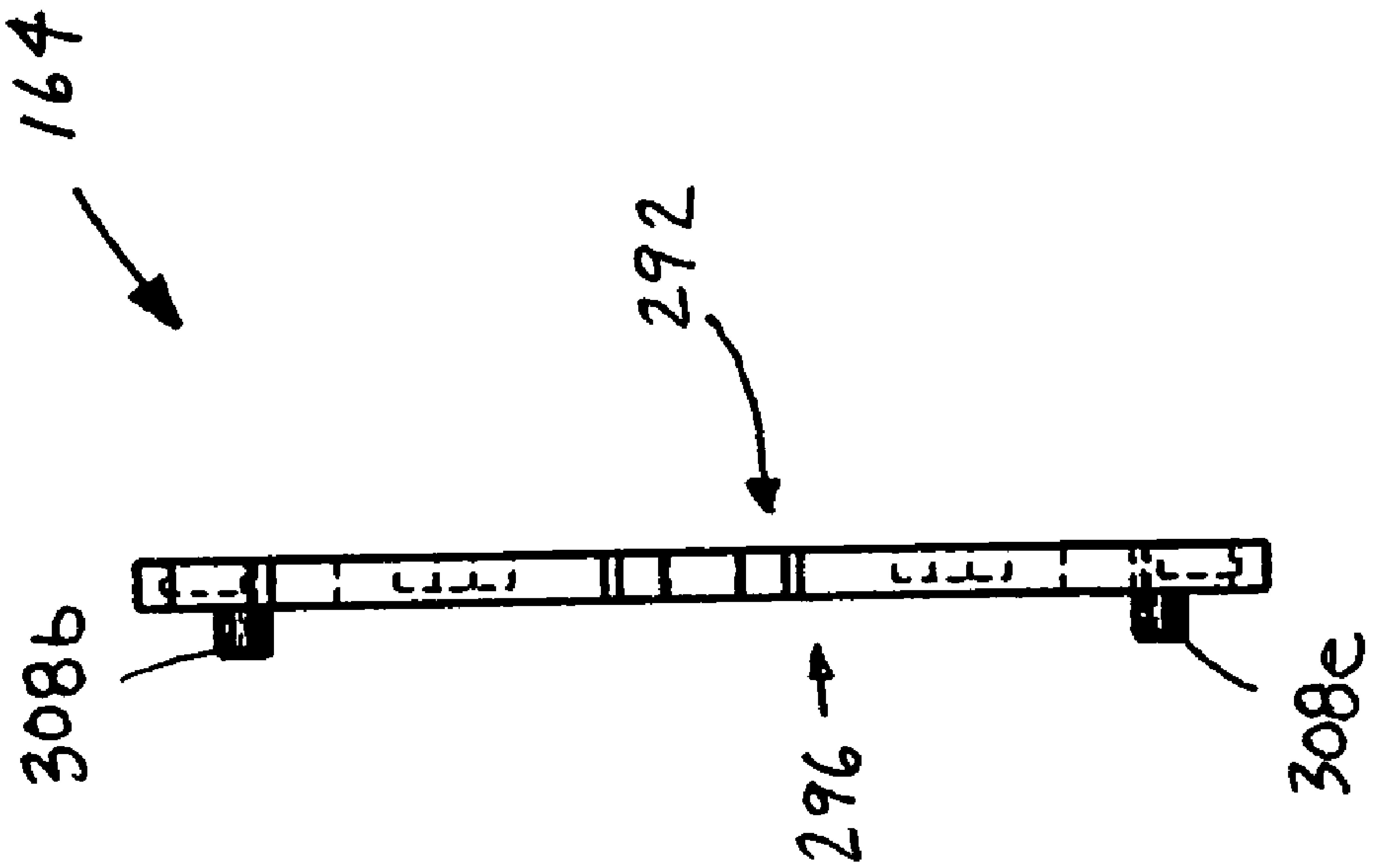


FIG. 17B

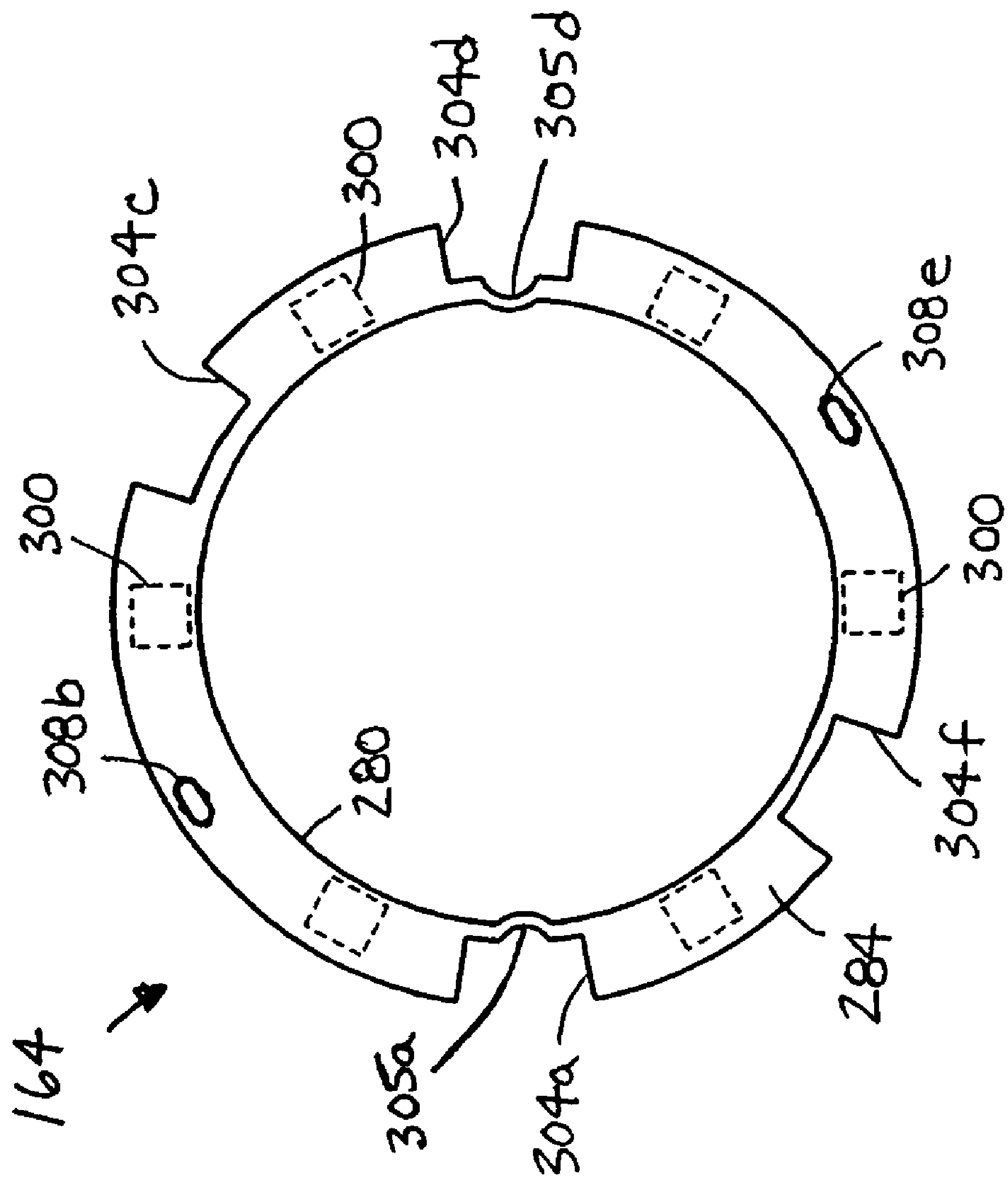


FIG. 17A

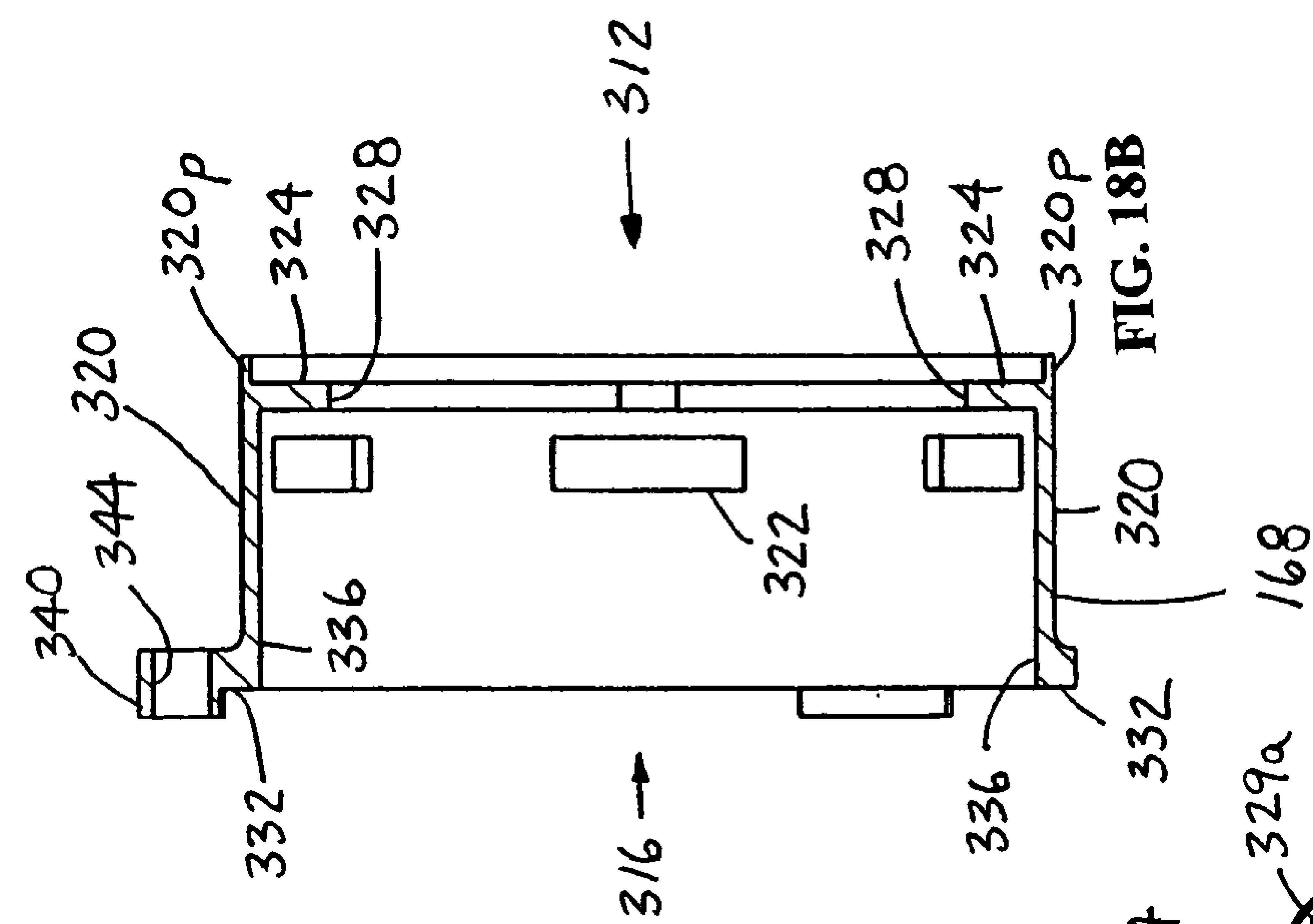


FIG. 18B

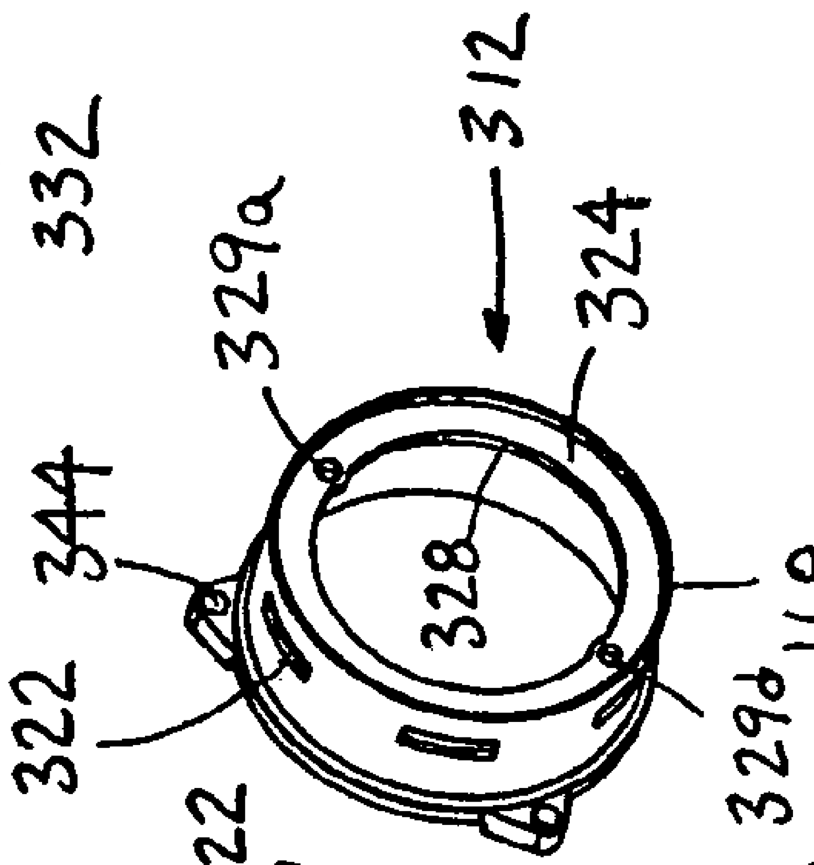


FIG. 18D

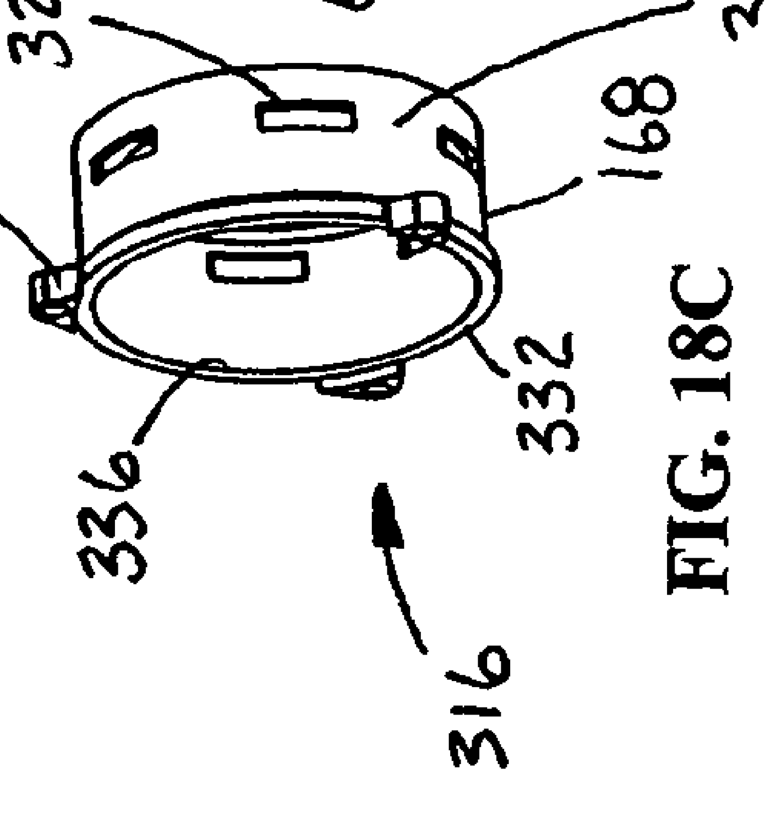


FIG. 18C

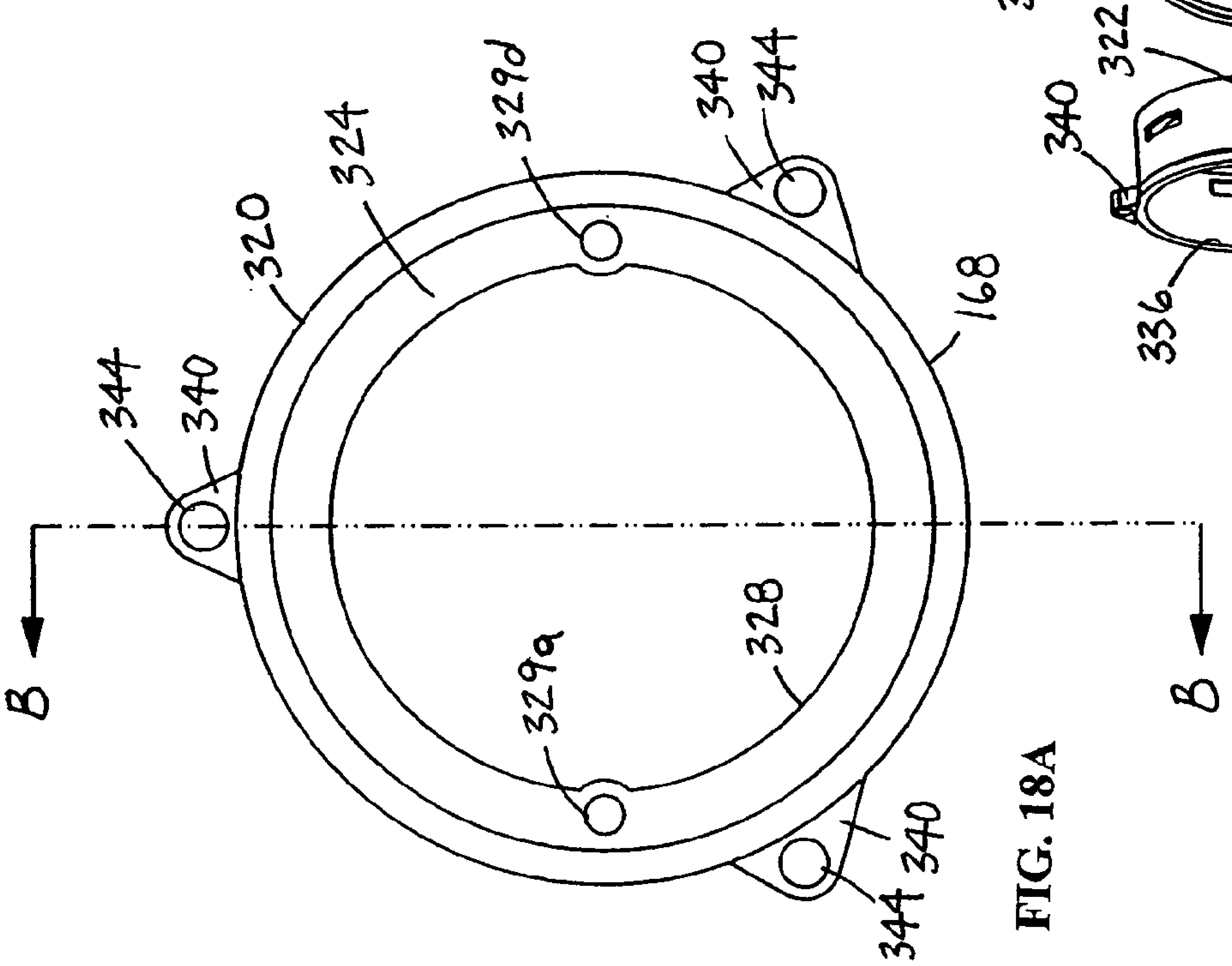


FIG. 18A

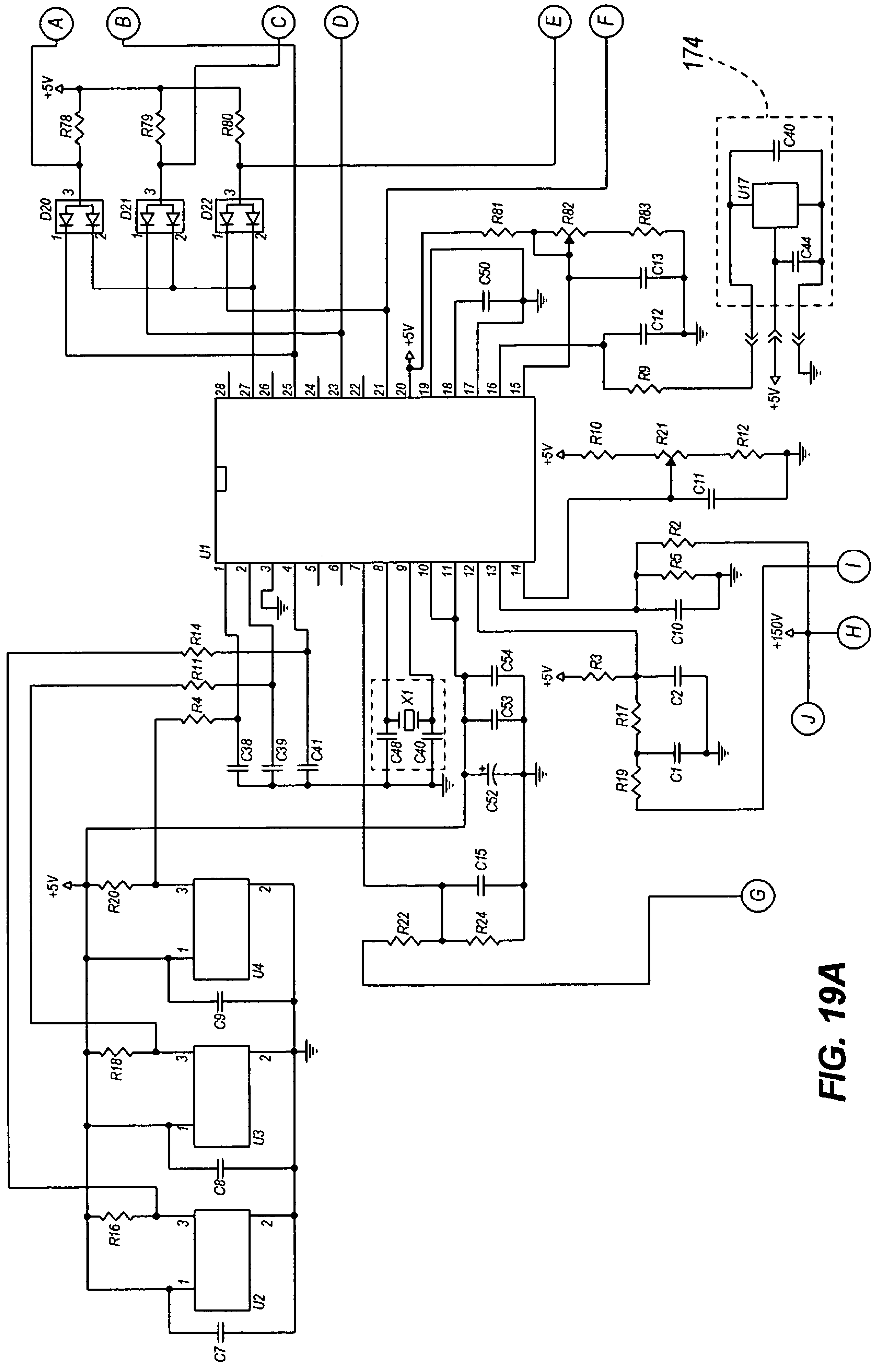

A
B
C
D
E
F
G
H
I
J
174
+5V
+150V
R78
R79
R80
D20
D21
D22
R81
R82
R83
C50
C13
C12
R9
C40
U17
C44
U1
R10
R21
R12
C11
R2
R5
C10
R3
C2
R17
C1
R19
R14
R11
R4
C38
C39
C41
X1
C48
C54
C53
C52
C15
R22
R24
R20
R18
R16
U4
U3
U2
C9
C8
C7

FIG. 19A

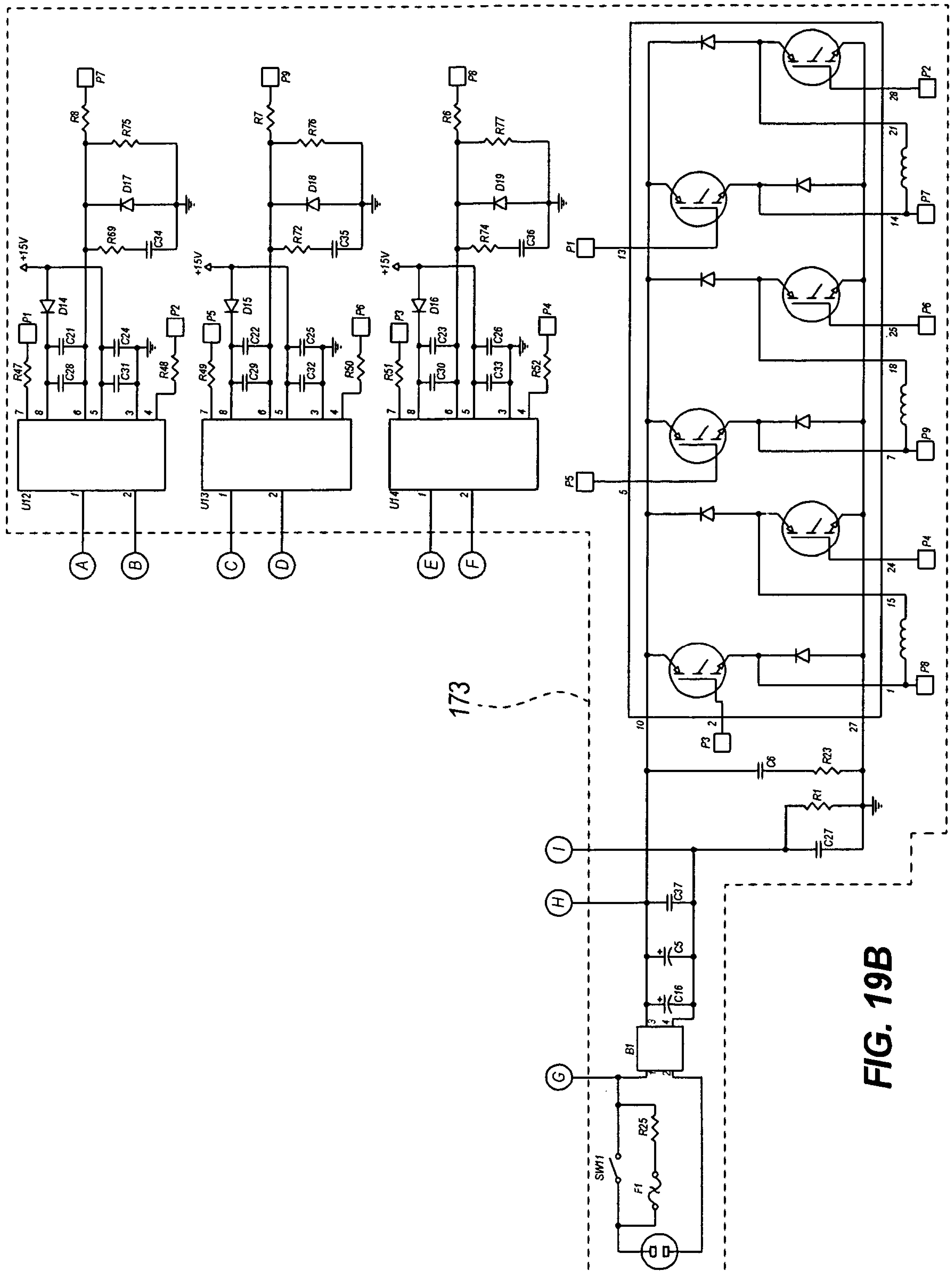
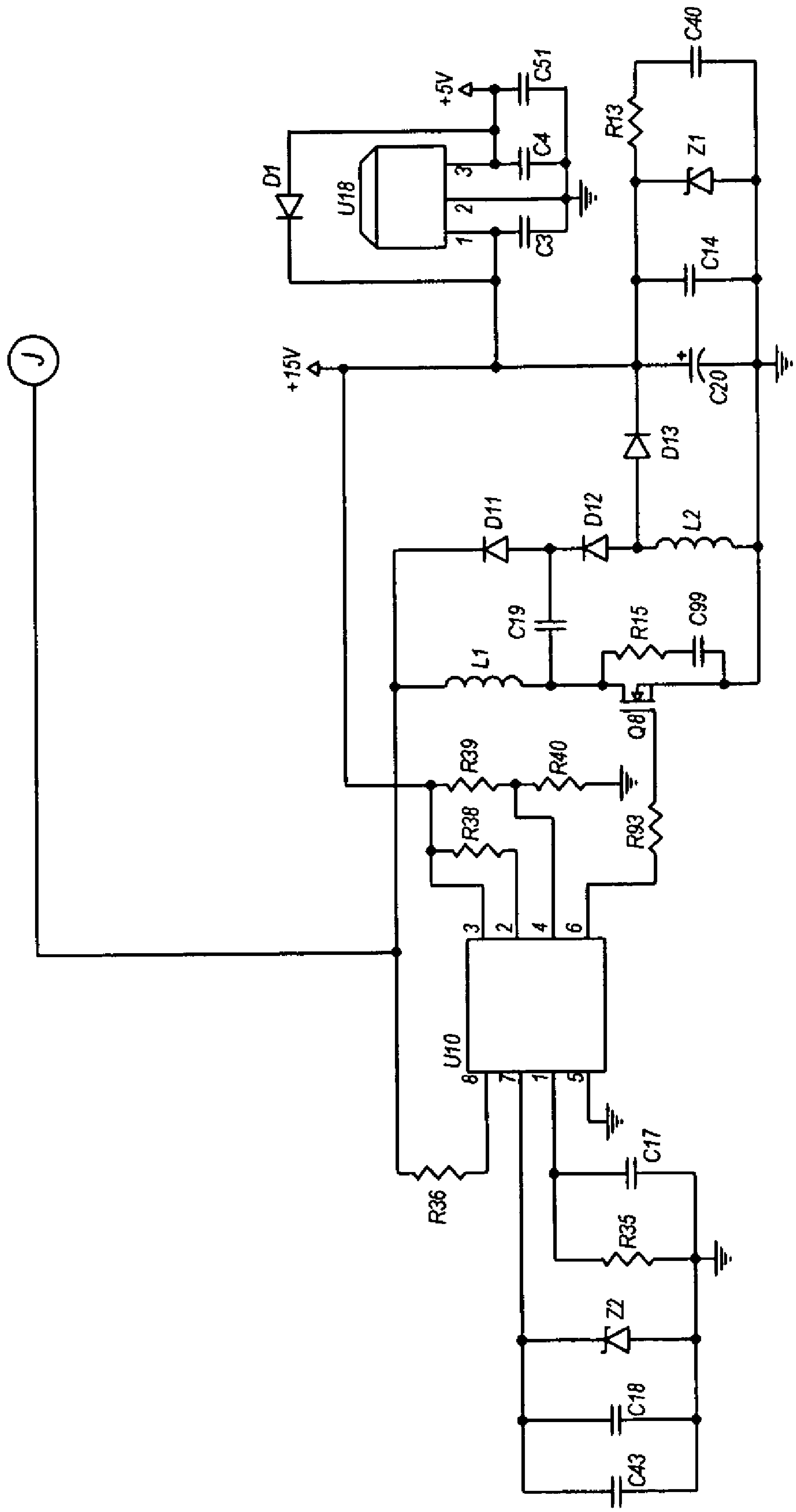

173
A
B
C
D
E
F
G
H
I
U12
U13
U14
B1
SW11
F1
R25
C16
C5
C37
C27
R1
C6
R23
+15V
D14
D15
D16
D17
D18
D19
P1
P2
P3
P4
P5
P6
P7
P8
P9

FIG. 19B



J
+15V
+5V
U18
D1
C51
C4
C3
C40
R13
Z1
C14
C20
D13
D11
D12
L2
C19
R15
C99
L1
Q8
R39
R40
R38
R93
U10
R36
R35
C17
Z2
C18
C43

FIG. 19C

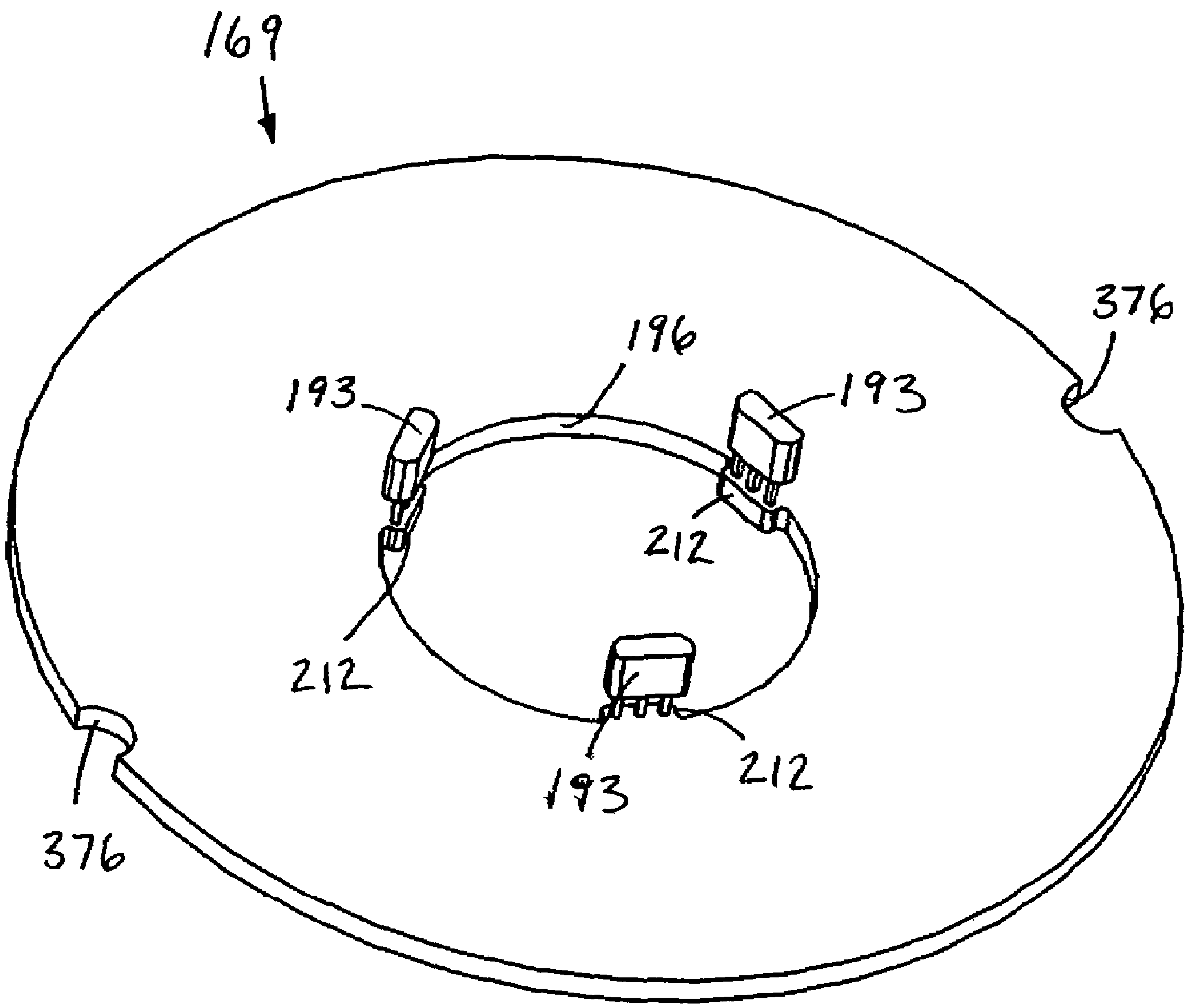


FIG. 20

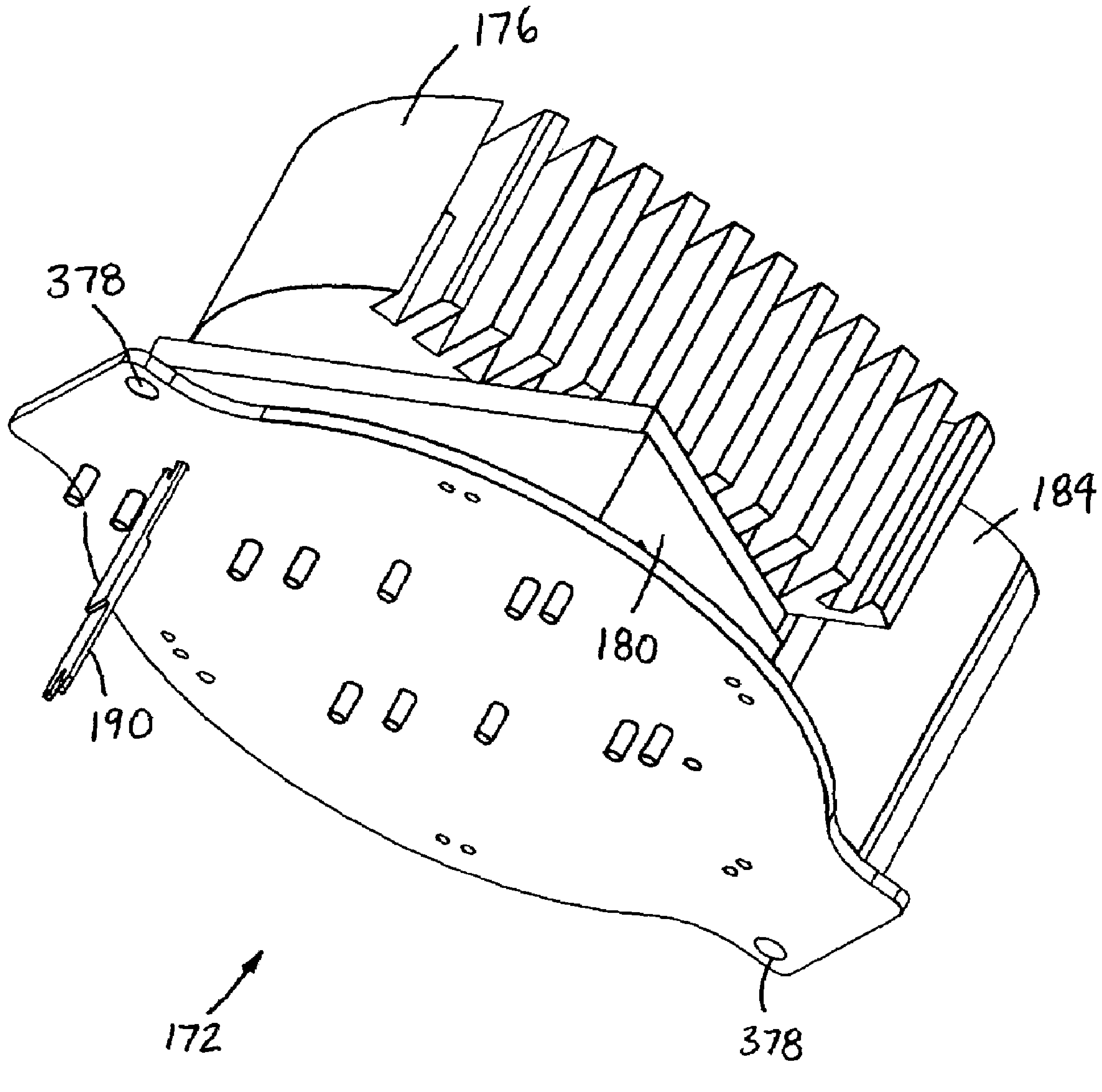


FIG. 21

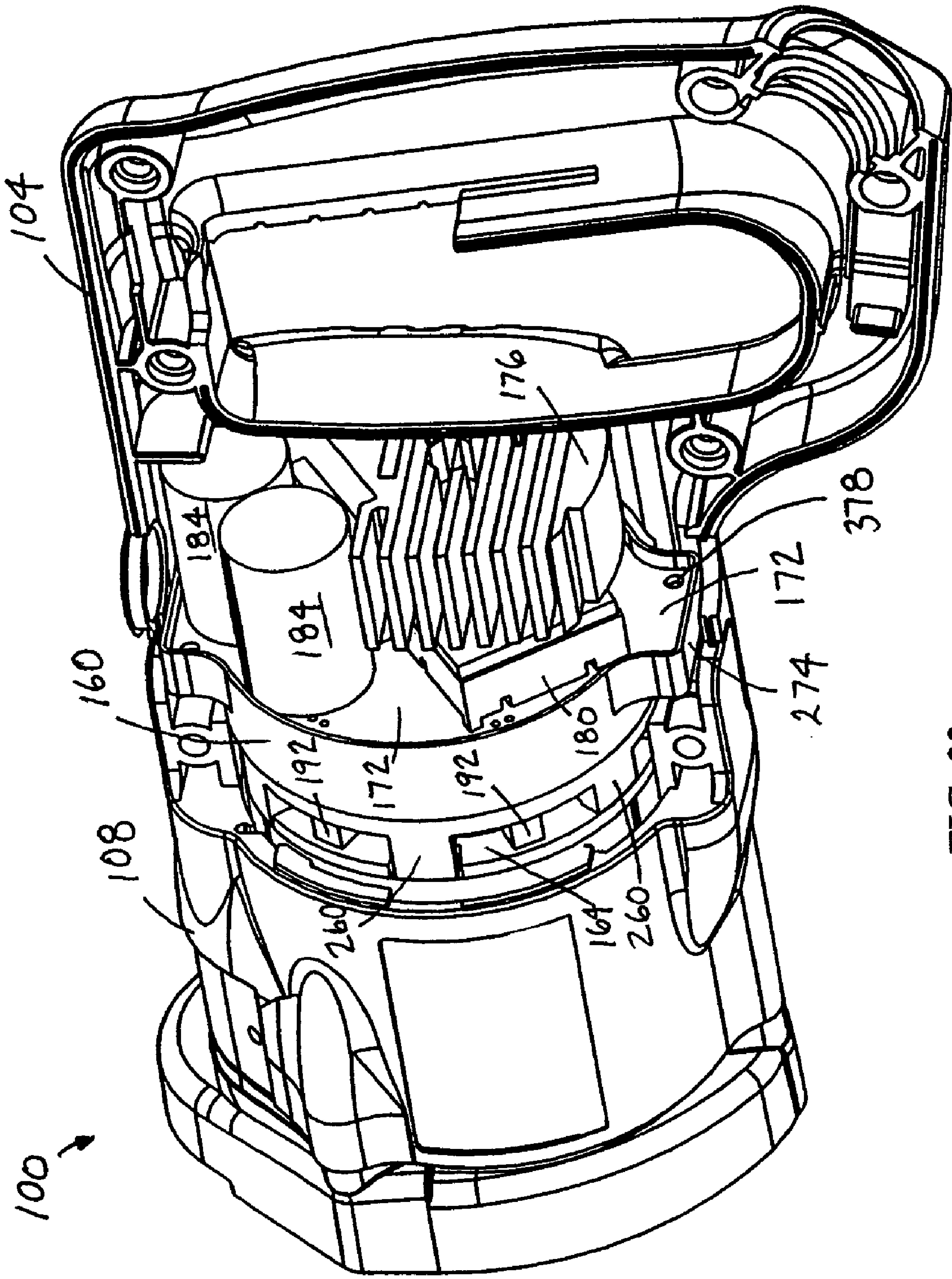
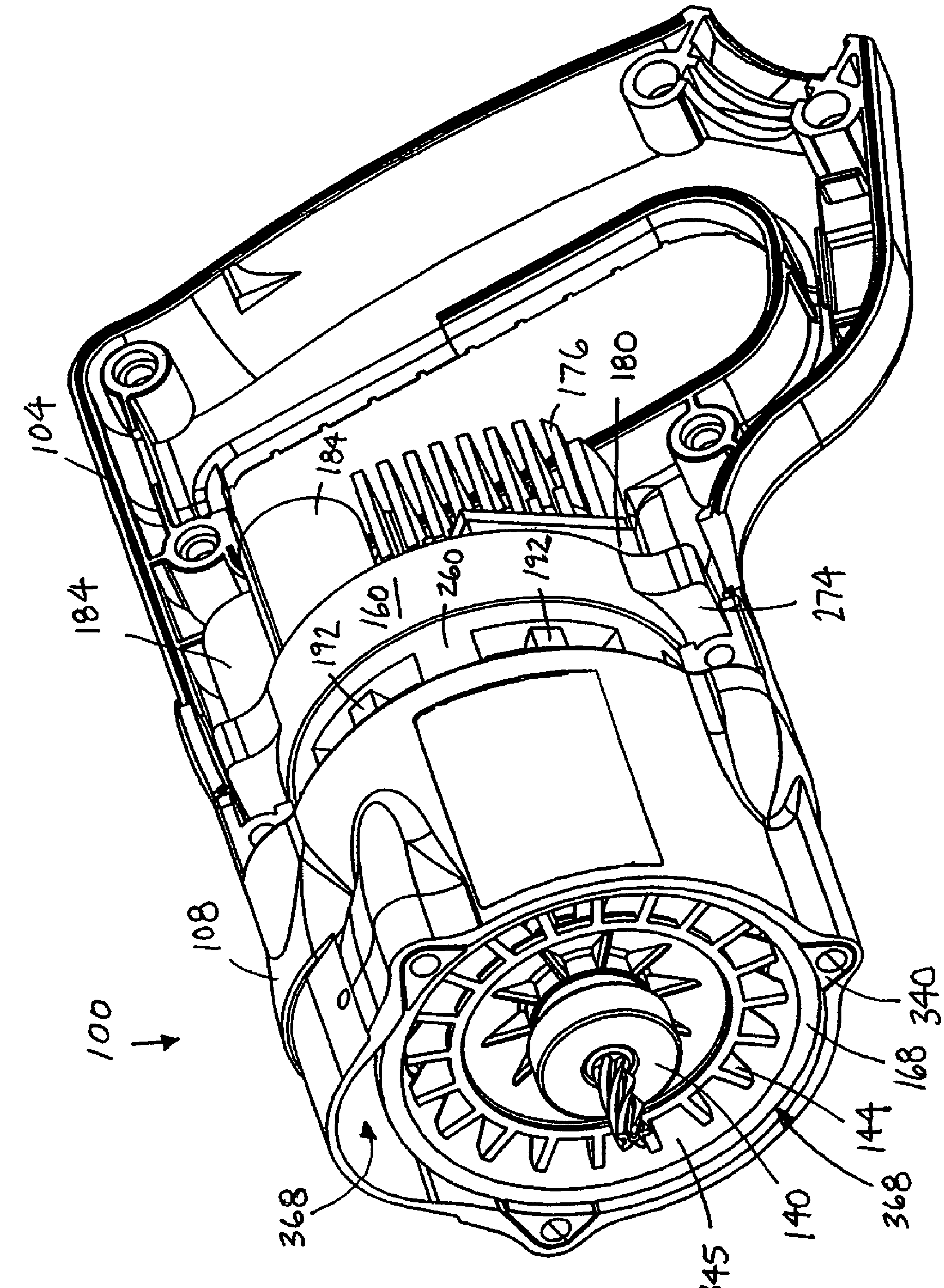

104
176
378
172
274
184
184
160
192
172
192
180
108
260
164
260
100

FIG. 22



104
184
176
180
184
192
160
260
192
274
108
100
340
168
144
368
140
345
368

FIG. 23

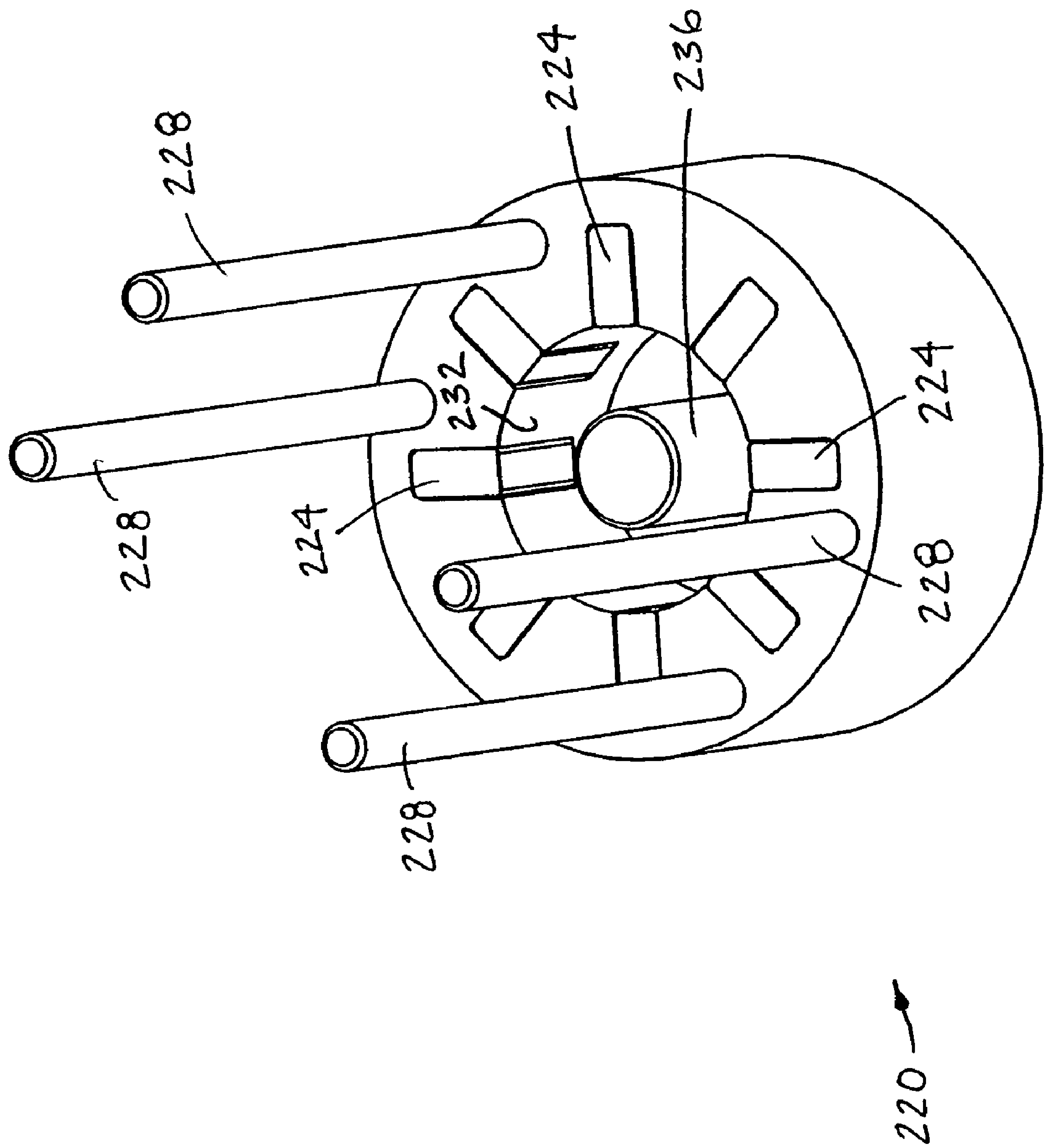


FIG. 24

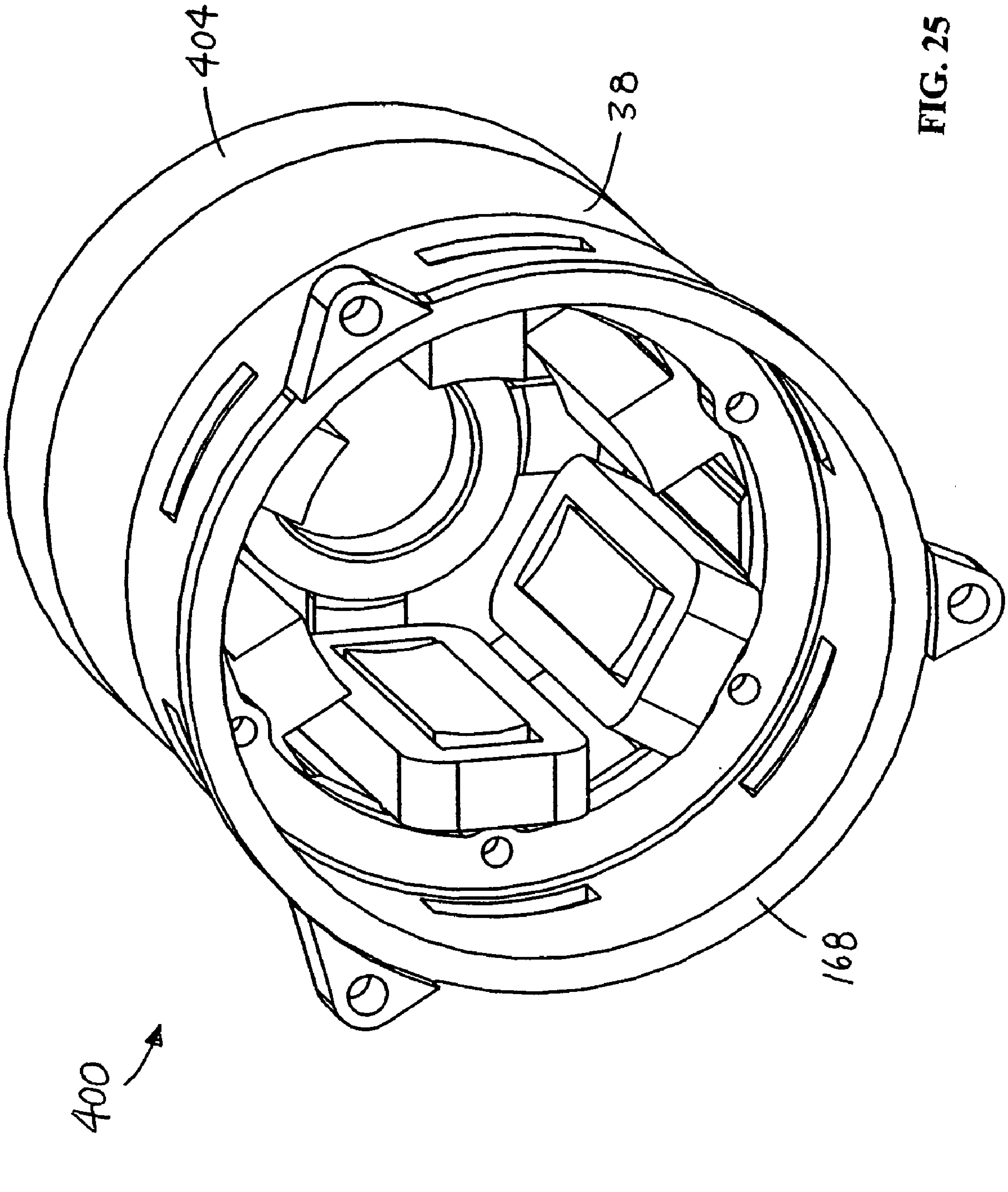


FIG. 25

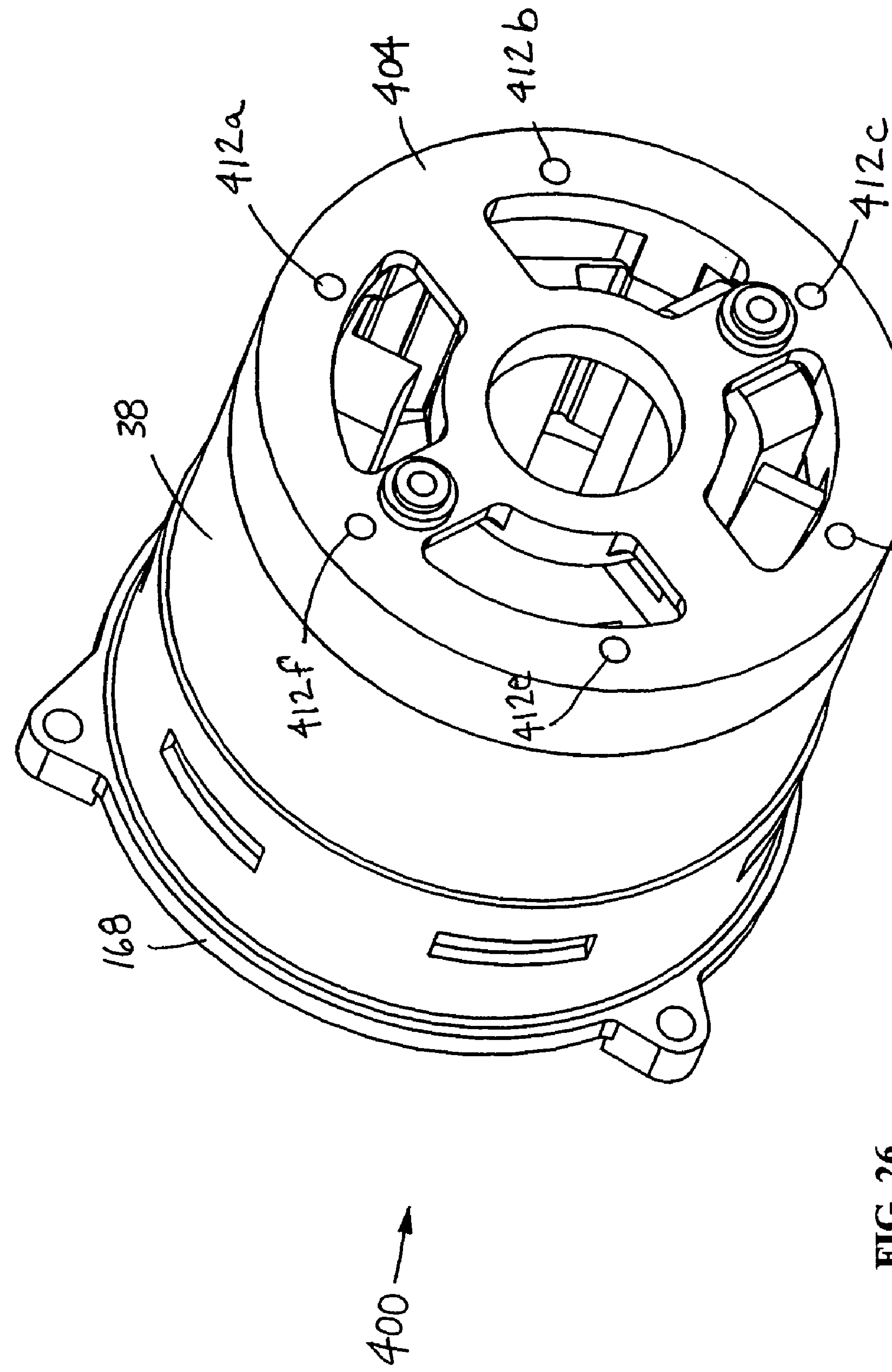


FIG. 26

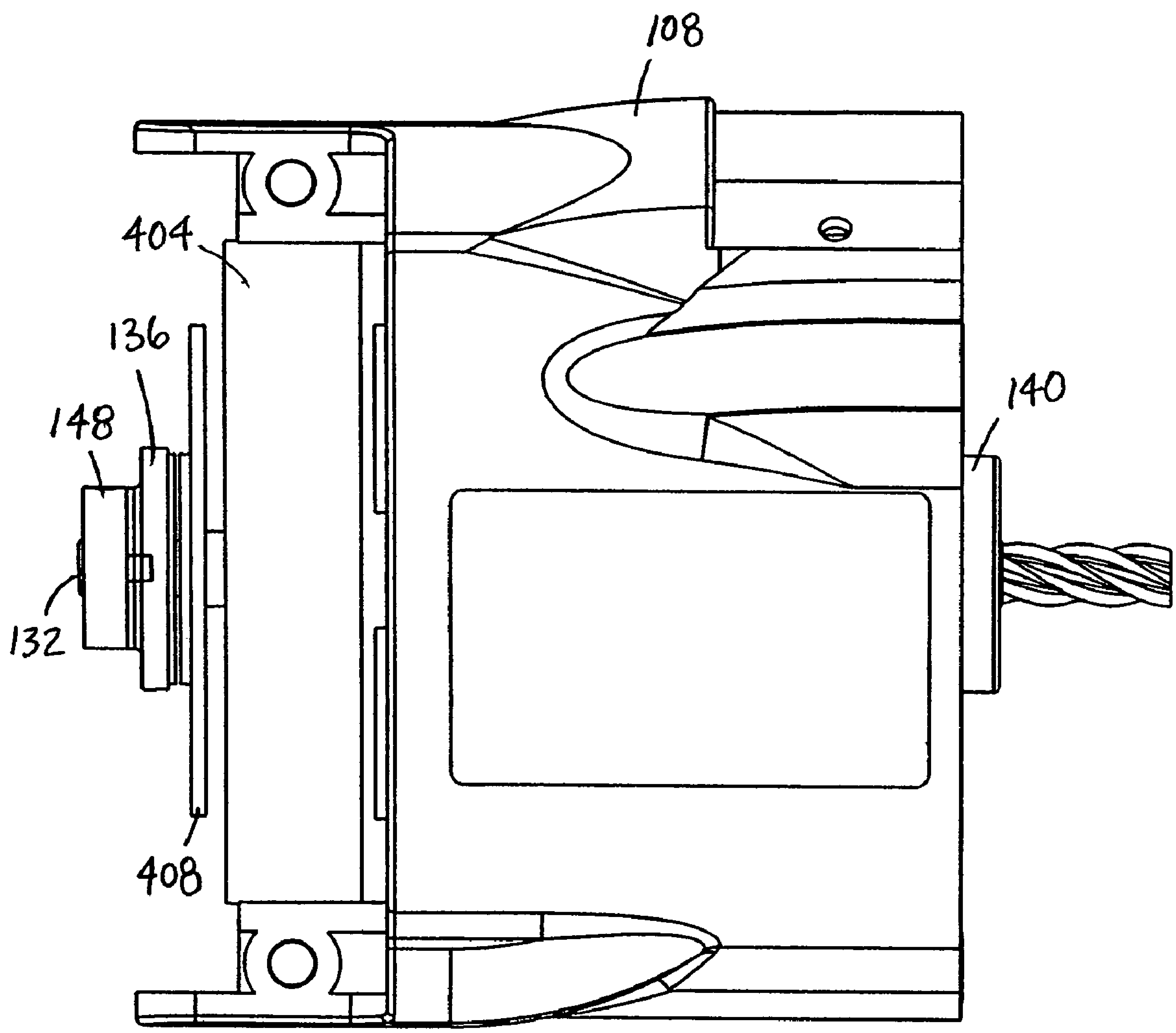


FIG. 27

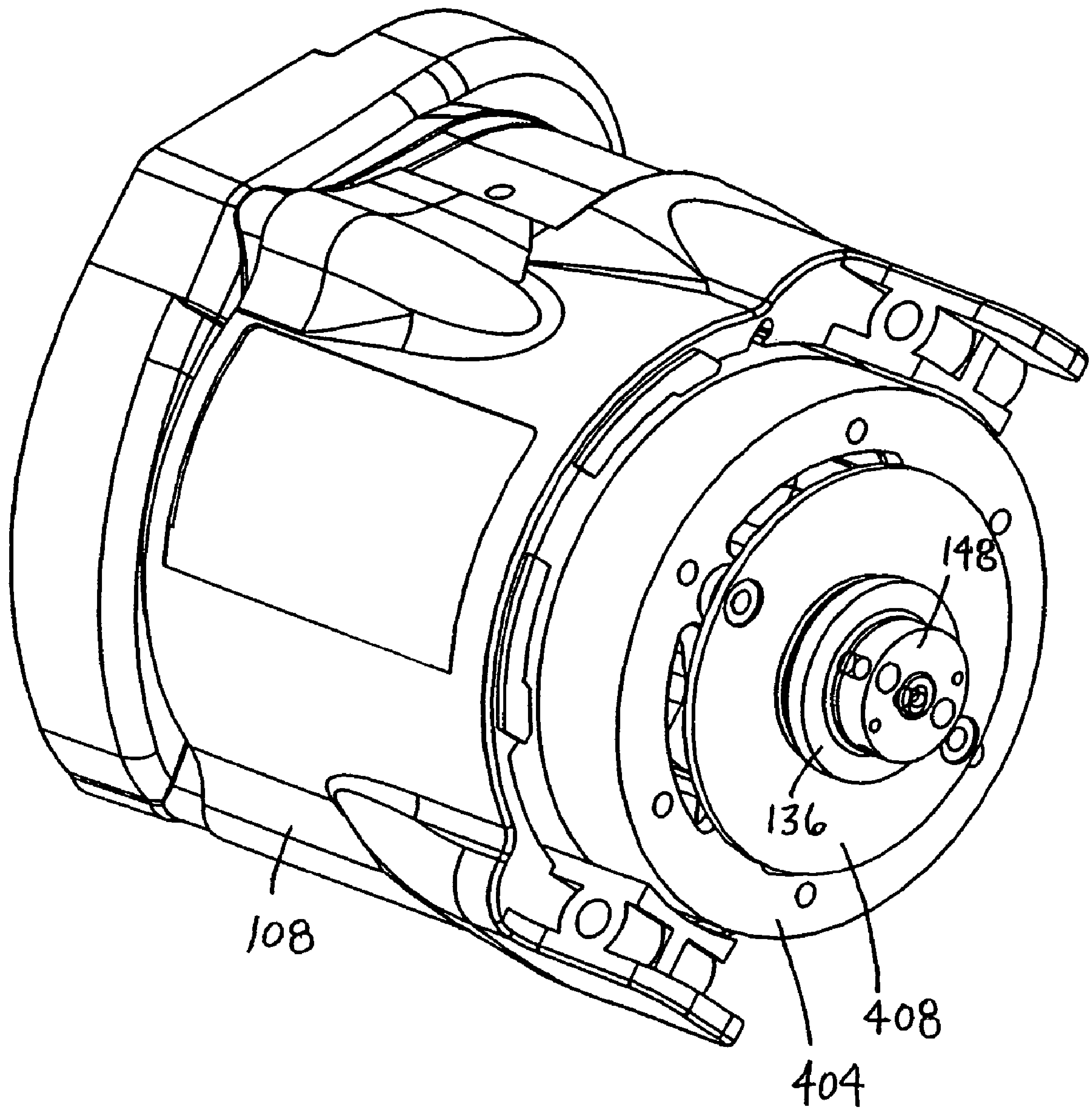
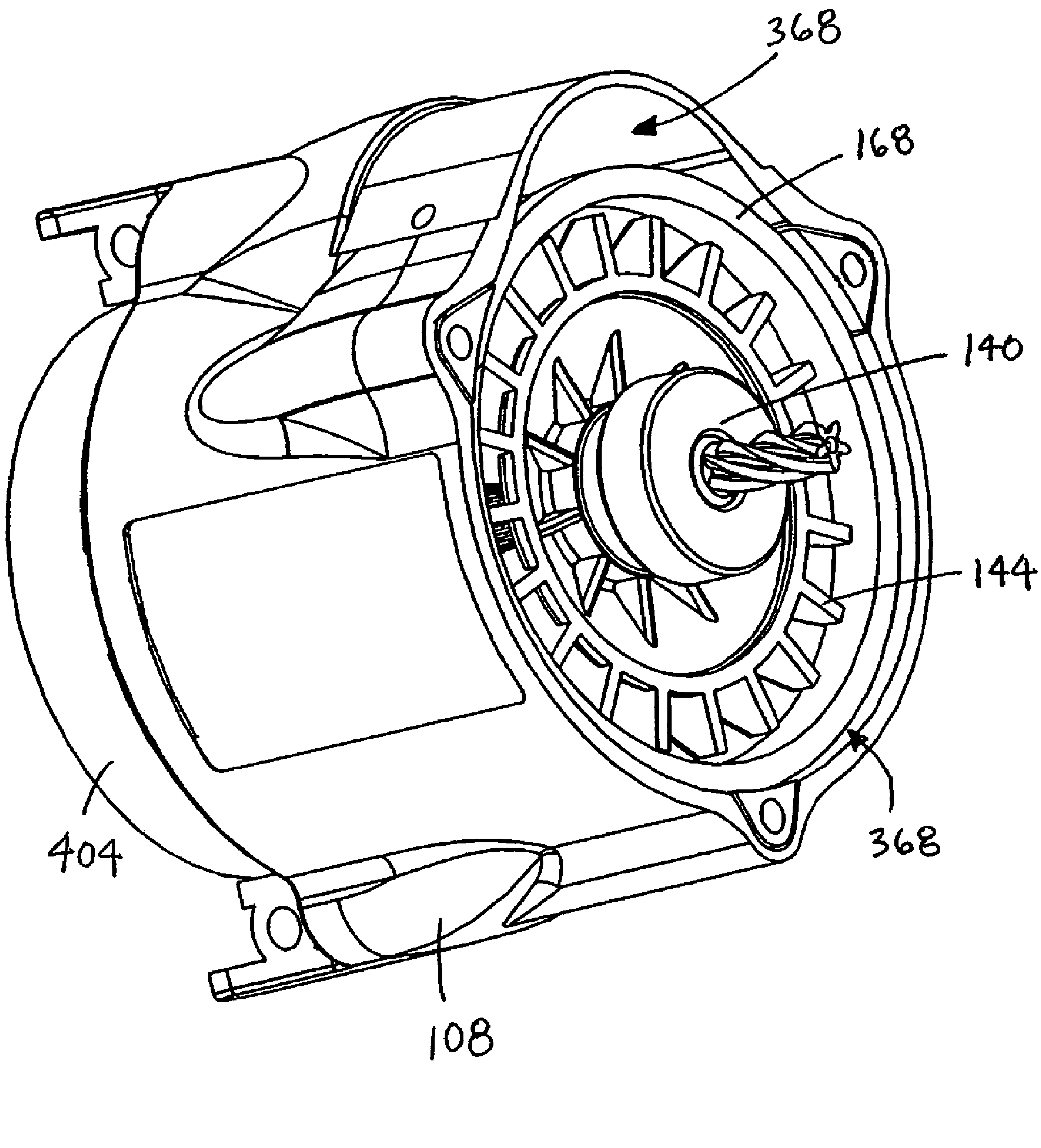


FIG. 28

FIG. 29



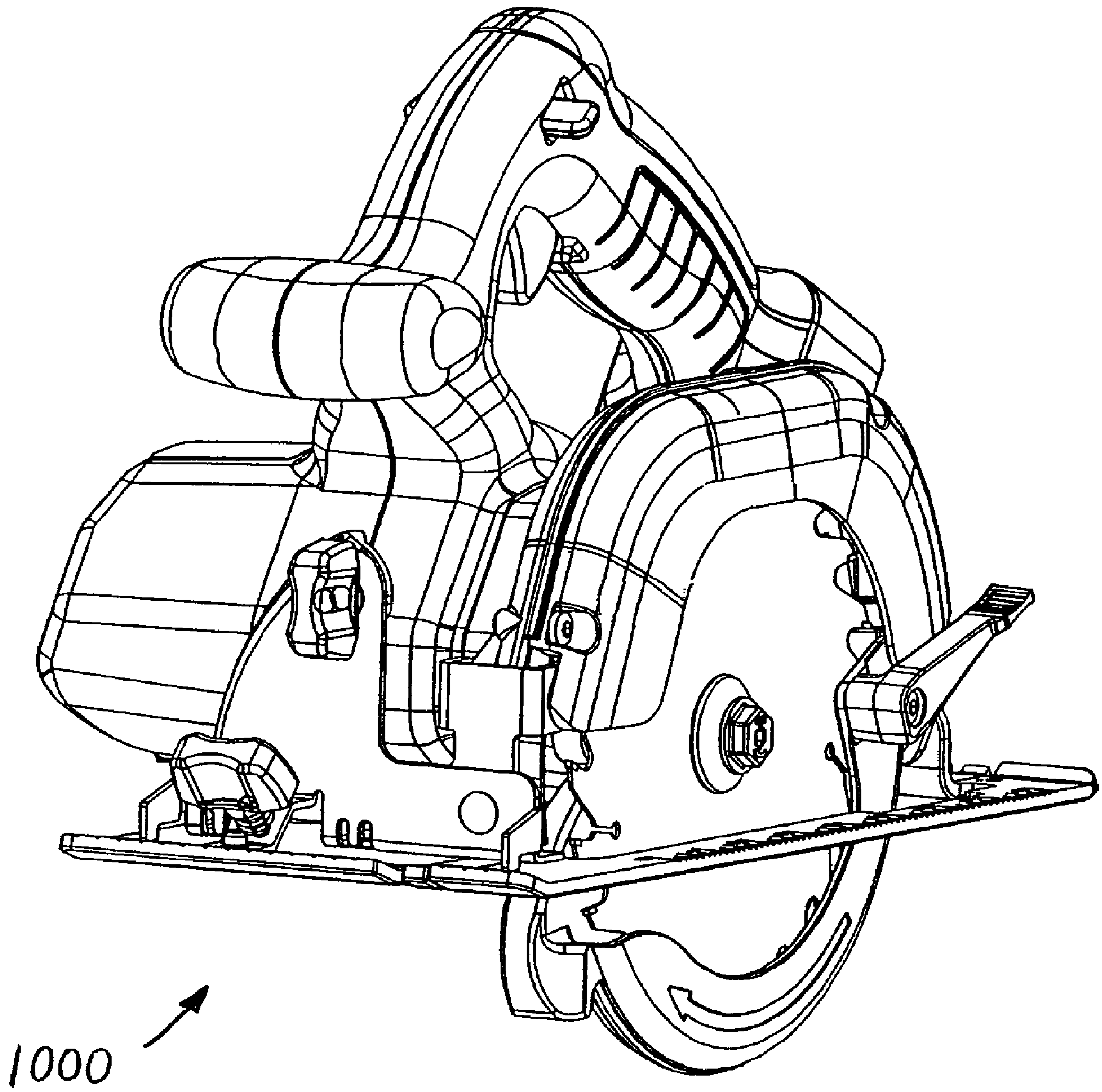


FIG. 30

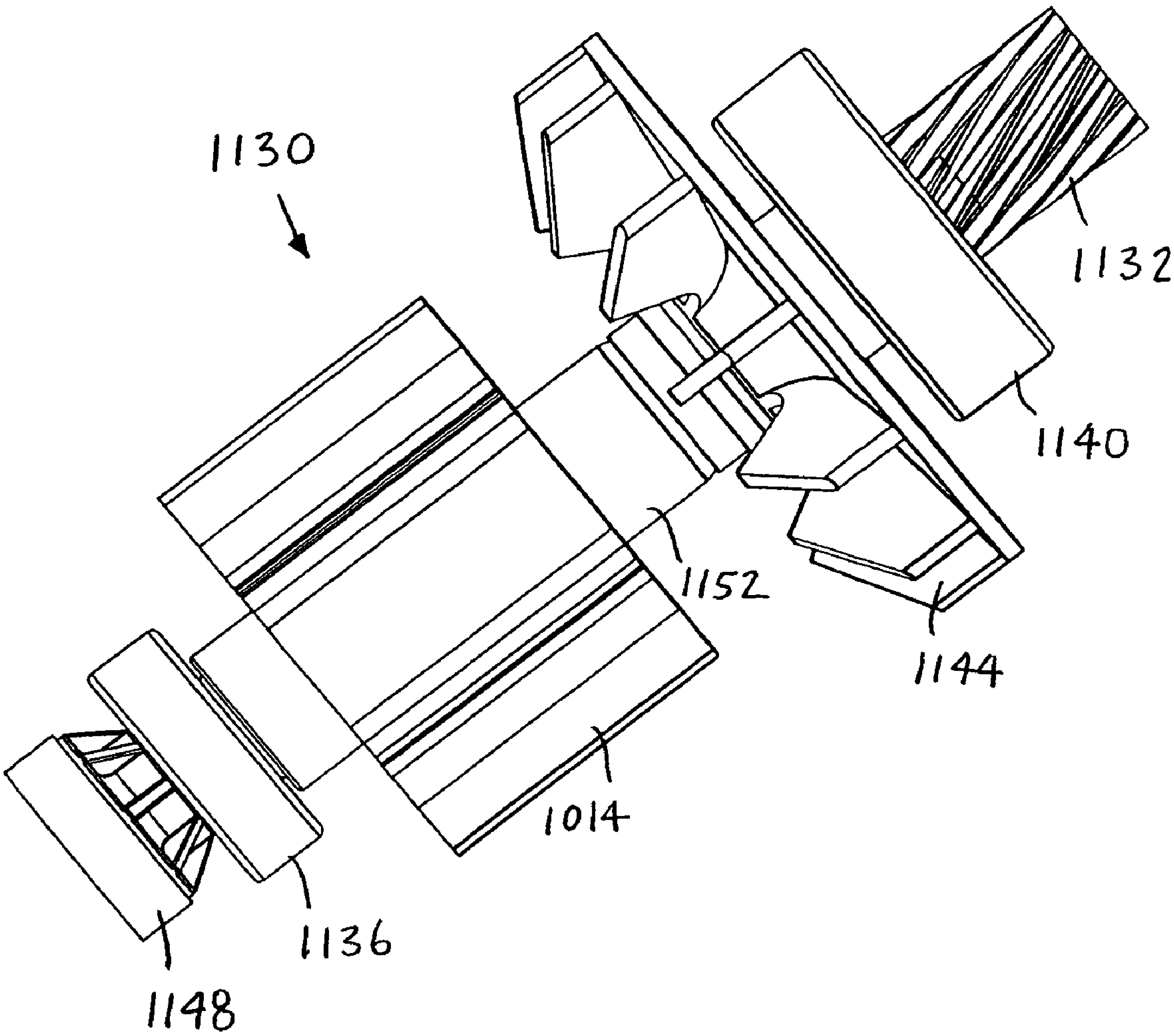


FIG. 31

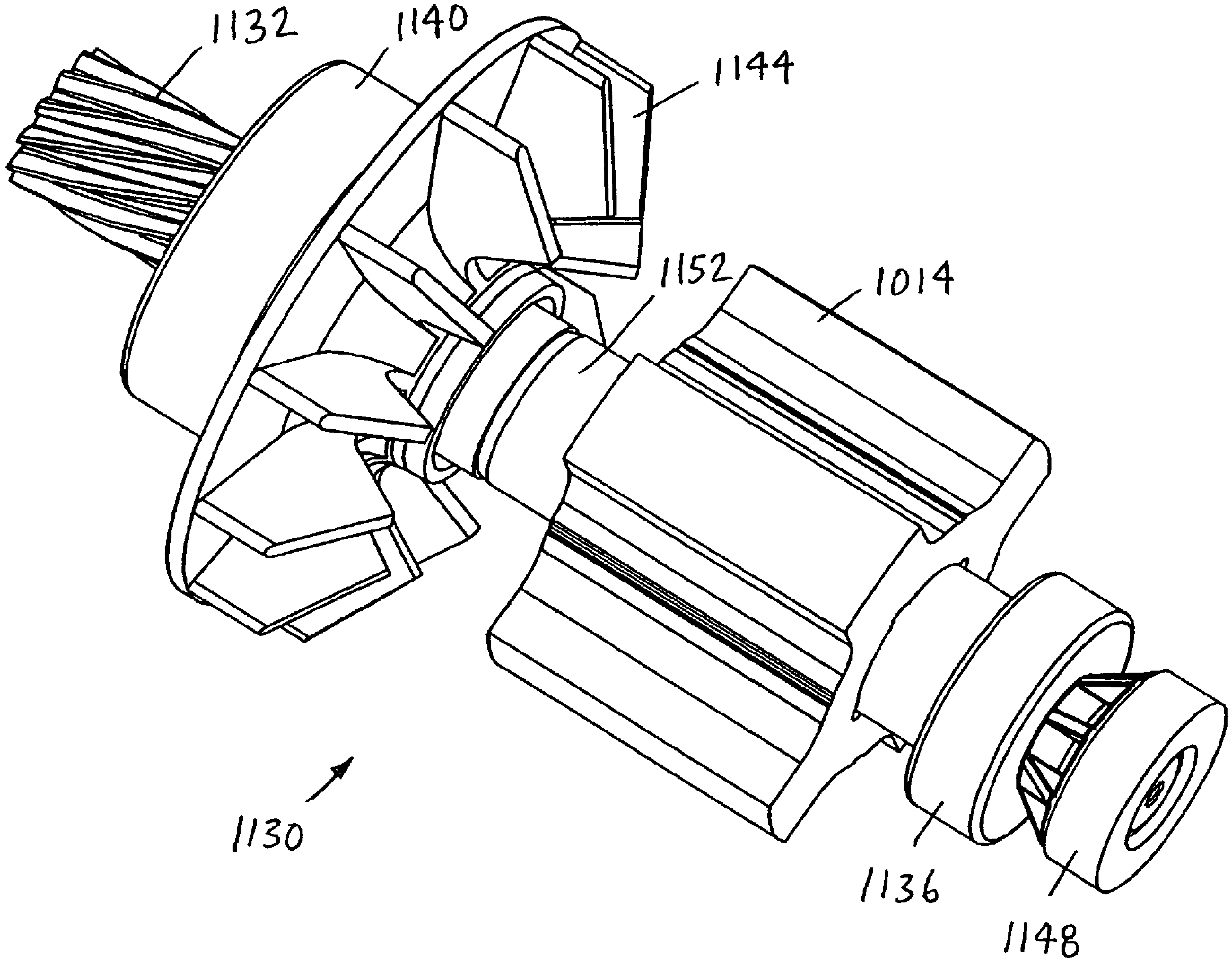


FIG. 32

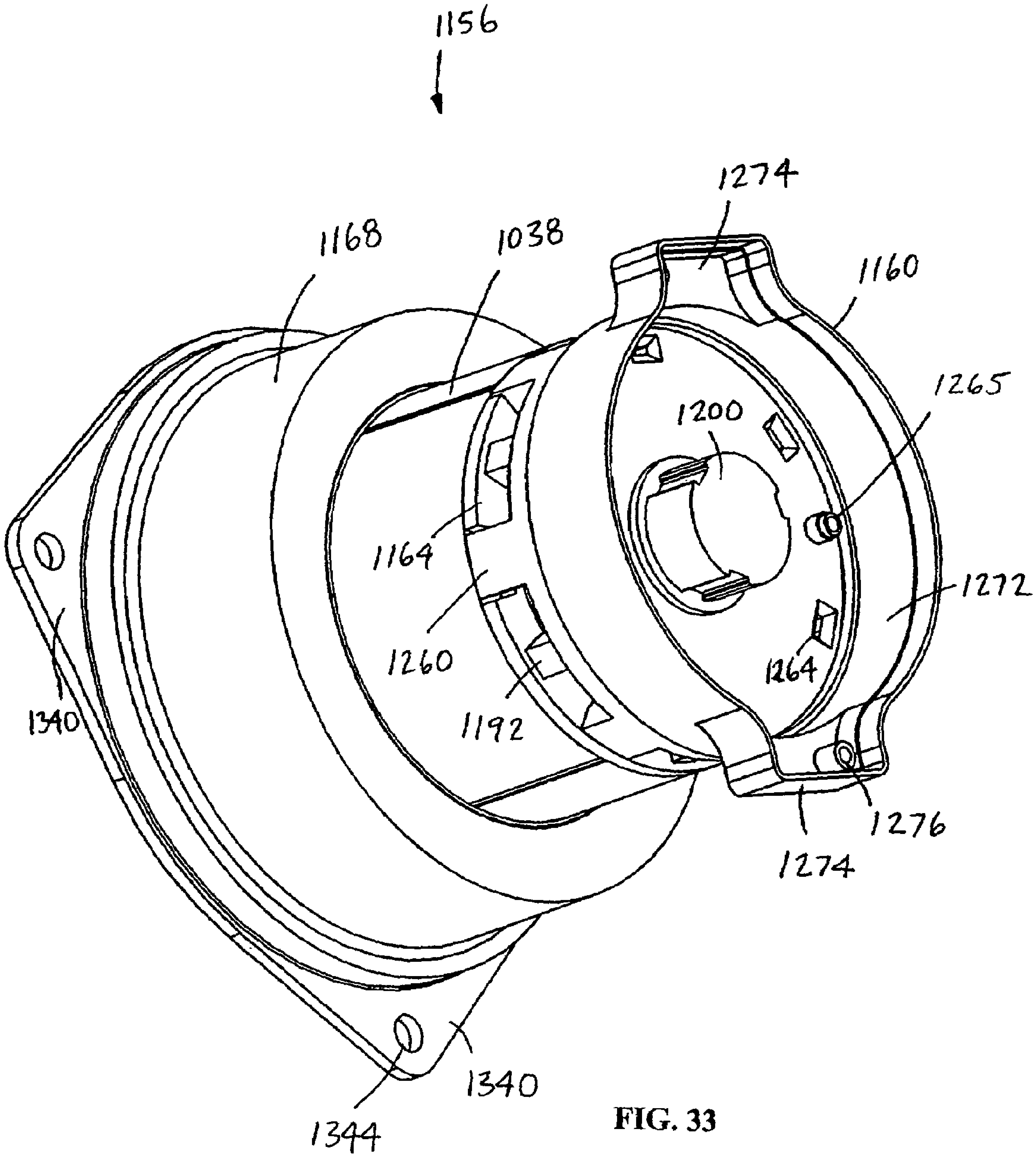

1156
1274
1168
1038
1160
1265
1200
1164
1272
1260
1264
1340
1192
1276
1274
1340
1344

FIG. 33

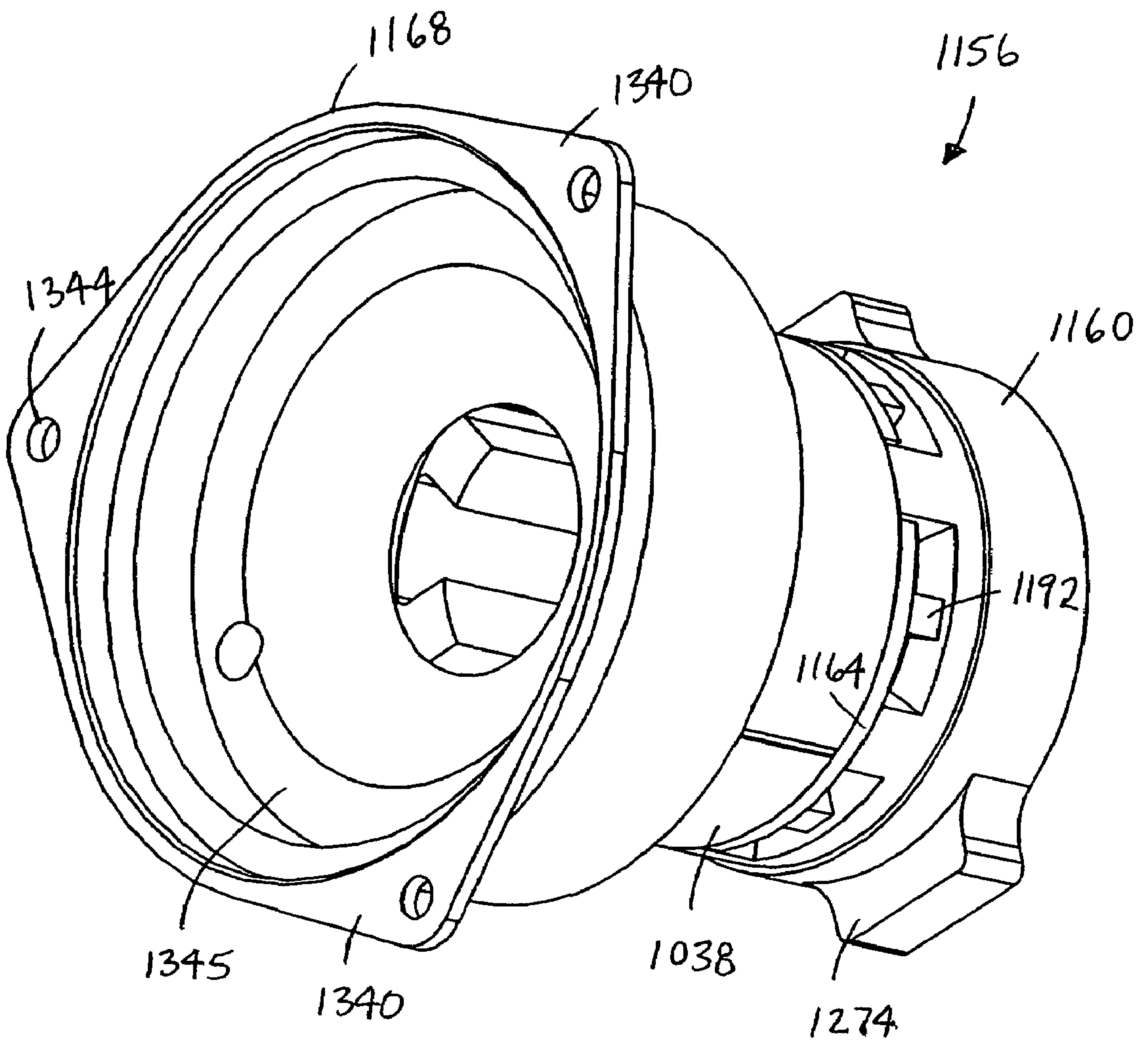


FIG. 34

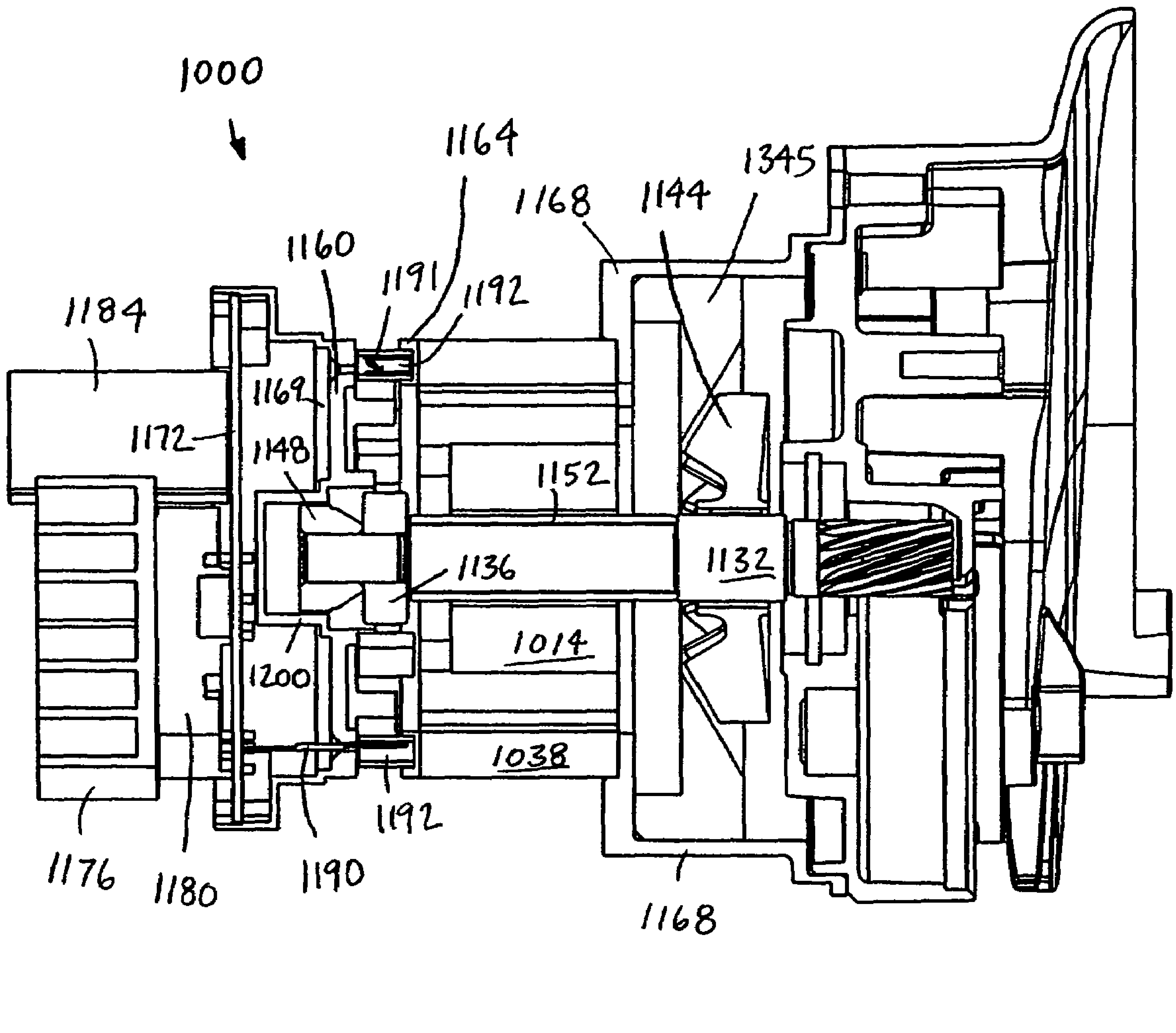

1000
1164
1345
1168
1144
1160
1191
1192
1184
1169
1172
1148
1152
1136
1132
1014
1200
1038
1192
1176
1180
1190
1168

FIG. 35

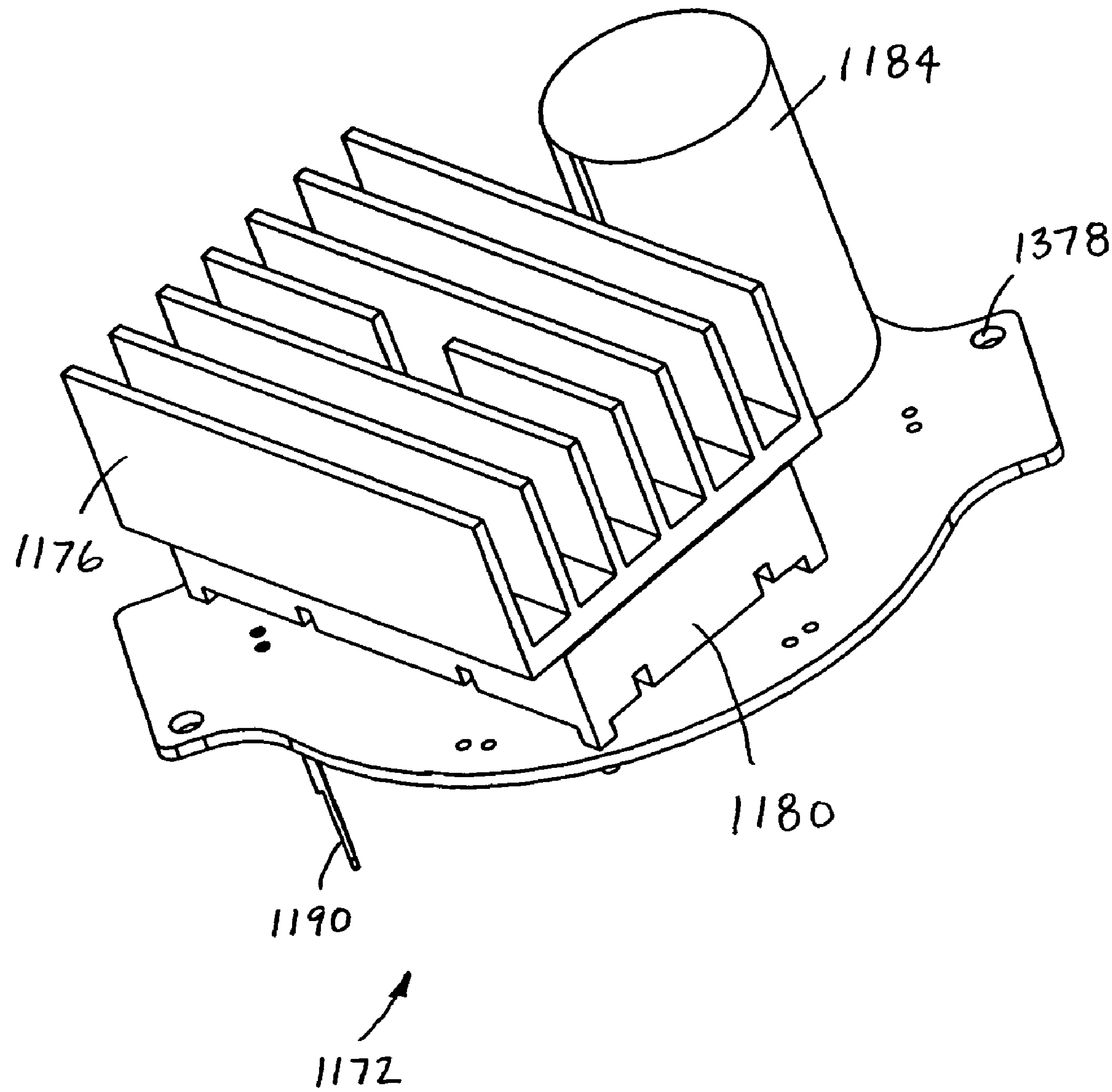


FIG. 36

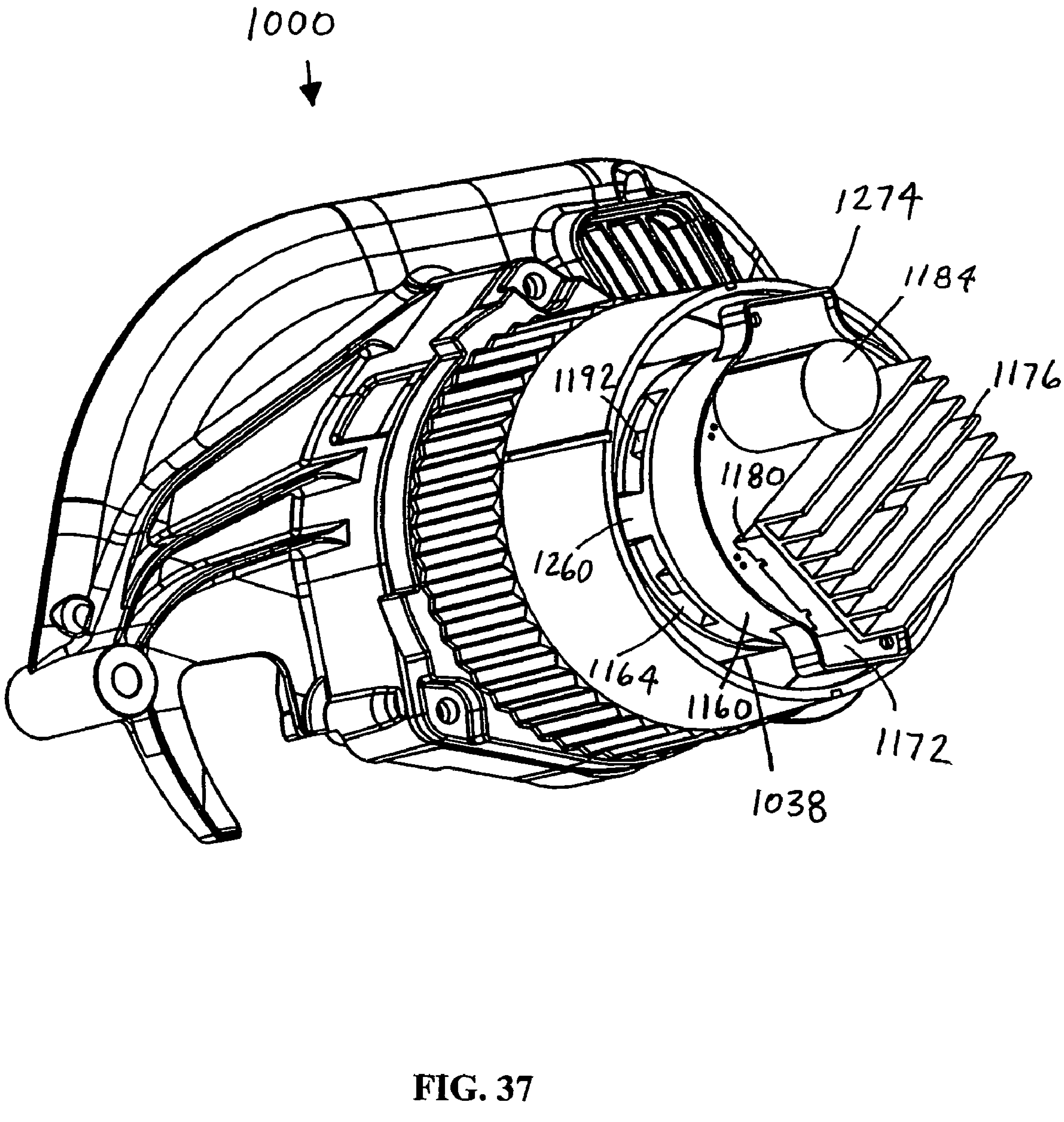


FIG. 37

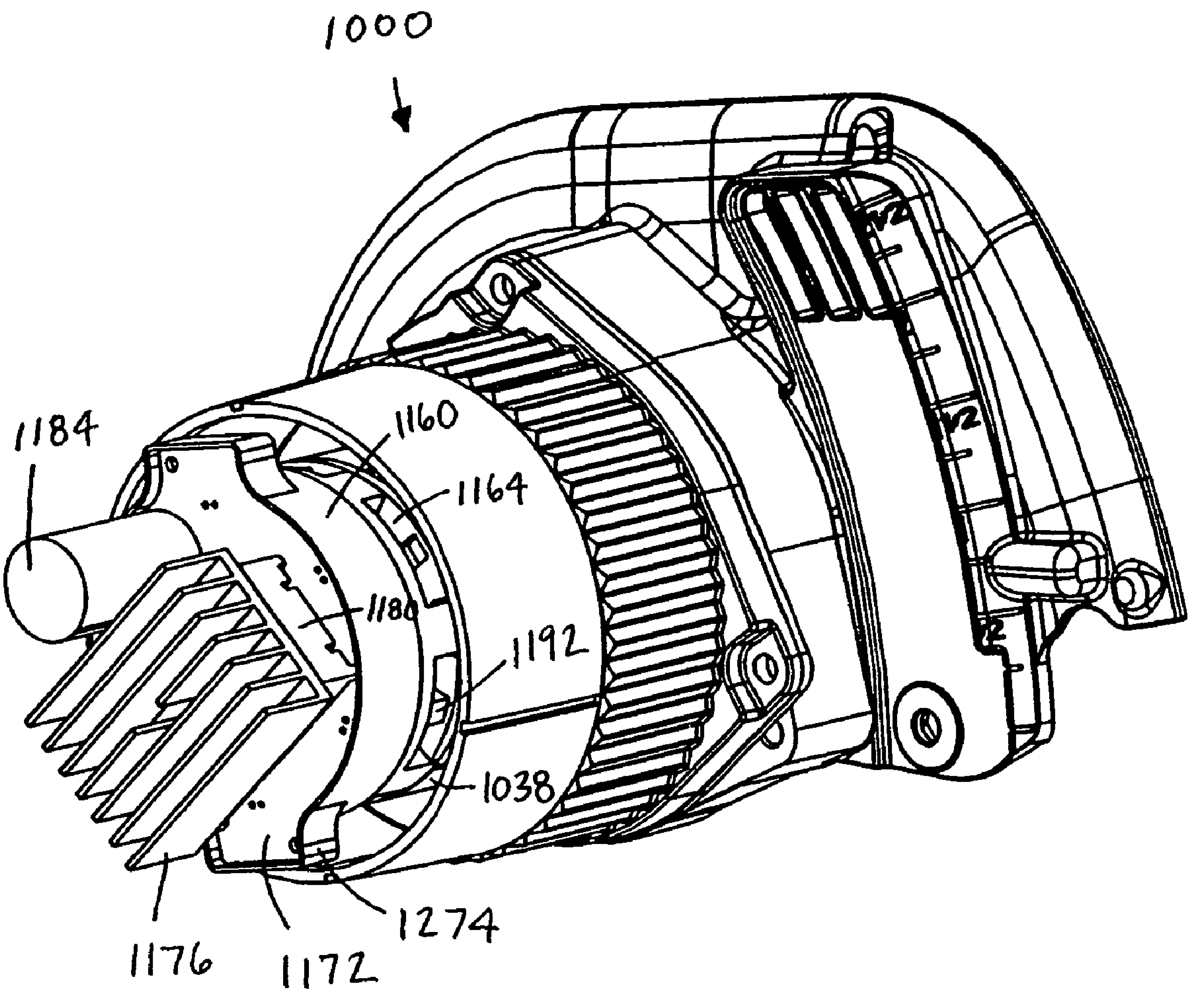


FIG. 38

POWER TOOLS WITH SWITCHED RELUCTANCE MOTOR

RELATED APPLICATIONS

This application is a continuation of prior filed patent application Ser. No. 10/357,729; filed on Feb. 4, 2003, now U.S. Pat. No. 7,064,462 which claims the benefit of Provisional Patent Application Ser. No. 60/354,253, filed Feb. 4, 2002, the entire contents of both of which are incorporated by reference herein.

FIELD OF THE INVENTION

The present invention relates to electrical devices that include a switched reluctance ("SR") motor and, more particularly, to power tools that include a SR motor.

BACKGROUND OF THE INVENTION

A typical SR motor includes multiple salient poles on both the stator and the rotor. Windings or coils are wound on the stator poles, and each pair of windings on diametrically opposite stator poles are connected in series or in parallel to form an electrically independent phase of the SR motor. The rotor is made of a magnetically permeable material such as, for example, a ferrous alloy. Electronics are utilized to energize the independent phases of the SR motor which thereby produce a magnetic field that interacts with the rotor poles to turn the rotor and the shaft to which the rotor is attached.

The simple design of SR motors is a feature which allows SR motors to generally last longer than other types of motors that are used in electrical devices. SR motors do not utilize permanent magnets, brushes and/or commutators as are typically used on the other types of motors. Elimination of these components reduces the maintenance needs and increases the life span of the SR motor when compared with the other types of motors.

SR motors also offer a number of other benefits over the other types of motors. These benefits include increased performance and a rugged construction for harsh environments. SR motors generally produce more torque than similarly sized models of the other types of motors. SR motors include efficiencies that are consistent over a wider range of operation and that are at least as good as the other types of motors. SR motors also include high speed and high acceleration capabilities. The benefits of SR motors make the use of SR motors desirable in a wide variety of electrical devices.

SUMMARY OF THE INVENTION

One type of electrical device that can benefit from the use of SR motors includes power tools and, more particularly, power tools configured to be hand-held during operation ("hand-held power tools"). Hand-held power tools generally include, for example, drills, circular saws, grinders, reciprocating saws, sanders, etc. These power tools typically include a housing that supports a drive unit (e.g., an electric motor) that is powered by a power source (e.g., an alternating current ("AC") corded power and/or a direct current ("DC") battery power) to drive a driven unit (e.g., a gearbox and an associated driven element such as a drill bit). The drive unit for these power tools is commonly a universal motor.

Although SR motors provide a number of benefits over the types of drive units currently used in hand-held power tools, a number of constraints have kept the SR motor from being utilized as a drive unit for such hand-held power tools. Hand-held power tools inherently need to be small enough that the operator can comfortably support and control the tool. Size and weight considerations typically dictate that such a power tool can be operated using a single hand under normal conditions. Some larger and more powerful hand-held power tools (e.g., a rotary hammer) may require two hands for operation. Regardless of the number of hands required for operation, space within the housing of these hand-held power tools is always a design consideration.

The small space design considerations result in problems when attempting to integrate a SR motor and the electronics associated with the SR motor into a hand-held power tool. The independent problems include, among others, those associated with heat dissipation, electrical noise, manufacturing tolerances, etc. SR motors are commonly used in applications including washing machines, compressors, blower units, automotive applications, etc. The space available in these applications commonly allows designers to integrate SR motors and the electronics associated with the SR motors into the device without experiencing many of the independent problems noted above with respect to the use of a SR motor and its associated electronics in a hand-held power tool.

Accordingly, in some aspects, the invention provides a hand-held power tool including a switched reluctance motor which substantially alleviates one or more of the above-described and other independent problems with existing SR motors and hand-held power tools.

In some aspects and in some constructions, the invention provides a construction that reduces tolerance stack-up. Manufacturing techniques that result in increased tolerance stack-up generally require components that have tolerances that are tighter than those tolerances required when increased tolerance stack-up is not present. Tighter tolerances therefore often correspond with higher manufacturing costs which thereby increase the overall cost of the electrical device the SR motor is integrated in.

In some aspects and in some constructions, the invention provides a self-contained electronics package that plugs into a SR motor to provide control functions to the SR motor. The electronics package can be quickly replaced and/or removed for service.

In some aspects and in some constructions, the invention provides enhanced cooling that keeps the electronics and the components of the SR motor cool for efficient operation.

In some aspects and in some constructions, the invention provides an encapsulated magnet that allows for contaminant free motor control over the life of the SR motor. The magnet is physically protected from contaminants such that contaminants cannot form on the magnet and thereby affect the motor control.

In some aspects and in some constructions, the invention provides an apparatus and a method for aligning magnet poles of a magnet hub with respect to the rotor poles the magnet poles represent.

The aspects of the invention that alleviate the integration problems for hand-held power tools may also provide benefits in electrical devices other than hand-held power tools. For example, the aspects may increase the efficiencies of the operation of SR motors used in other electrical devices and/or reduce costs associated with producing and/or servicing the SR motors and the electronics associated with the SR motors of the other electrical devices. Additionally, some aspects of the invention may further be applicable for use in electrical devices that utilize other types of motors.

It is an independent advantage of the invention to provide a power tool that is configured to be hand-held during operation that is driven by a switched reluctance motor. It is an independent advantage of the invention to provide a construction that reduces tolerance stack-up. Also, it is an independent advantage of the invention to provide a self-contained electronics package that plugs into a SR motor to provide control functions to the SR motor. In addition, it is an independent advantage of the invention to provide enhanced cooling that keeps the electronics and the components of the SR motor cool for efficient operation. Further, it is an independent advantage of the invention to provide an encapsulated magnet that allows for contaminant free motor control over the life of the SR motor. It is an independent advantage to provide an apparatus and a method for aligning magnet poles of a magnet hub with respect to the rotor poles the magnet poles represent.

Other independent features and independent advantages of the invention will become apparent to those skilled in the art upon review of the following detailed description, claims, and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is a perspective view of an electrical device embodying the invention.

FIG. **2** is a simplified schematic representation of a switched reluctance motor.

FIGS. **3**A, **3**B, and **3**C illustrate a rotor construction of the switched reluctance motor of FIG. **2**.

FIG. **4** illustrates a perspective view of a stator of the switched reluctance motor of FIG. **2**.

FIGS. **5**A, **5**B, and **5**C illustrate a stator construction of the switched reluctance motor of FIG. **2**.

FIG. **6** illustrates a perspective view of a rotor assembly of the electrical device illustrated in FIG. **1**.

FIG. **7** illustrates the rotor assembly of FIG. **6** including a magnet hub and a shaft tube.

FIG. **8** illustrates an exploded view of the rotor assembly of FIG. **7**.

FIG. **9** illustrates a side view of the rotor assembly of FIG. **7**.

FIGS. **10** and **11** illustrate perspective views of a stator assembly of the electrical device illustrated in FIG. **1**.

FIG. **12** illustrates an exploded view of the stator assembly of FIGS. **10** and **11**.

FIGS. **13**A and **13**B illustrate a side and an end view of the stator assembly of FIGS. **10** and **11**.

FIGS. **14**A, **14**B, **14**C, **14**D, **14**E, and **14**F illustrate a rear bell of the stator assembly of FIGS. **10** and **11**.

FIGS. **15** and **16** illustrate partial sectional views of the electrical device illustrated in FIG. **1**.

FIGS. **17**A and **17**B illustrate an end and a side view of a terminal board of the stator assembly of FIGS. **10** and **11**.

FIGS. **18**A, **18**B, **18**C, and **18**D illustrate a front bell of the stator assembly of FIGS. **10** and **11**.

FIGS. **19**A-C illustrate a schematic diagram of an electronics package of the electrical device of FIG. **1**.

FIG. **20** illustrates a perspective view of a first printed circuit board of the electronics package illustrated in FIGS. **19**A-C.

FIG. **21** illustrates a perspective view of a second printed circuit board of the electronics package illustrated in FIGS. **19**A-C.

FIGS. **22** and **23** illustrate partial assemblies of the electrical device illustrated in FIG. **1**.

FIG. **24** illustrates a fixture for coupling a magnet hub to a rotor assembly.

FIGS. **25**, **26**, **27**, **28**, and **29** illustrate an alternate construction of a portion of the electrical device illustrated in FIG. **1**

FIG. **30** is a perspective view of an electrical device embodying the invention.

FIGS. **31** and **32** illustrate perspective views of a rotor assembly of the electrical device illustrated in FIG. **30**.

FIGS. **33** and **34** illustrates perspective views of a stator assembly of the electrical device illustrated in FIG. **30**.

FIG. **35** illustrates a partial sectional view of the electrical device illustrated in FIG. **30**.

FIG. **36** illustrates a perspective view of a printed circuit board of the electrical device illustrated in FIG. **30**.

FIGS. **37** and **38** illustrate partial assemblies of the electrical device illustrated in FIG. **30**.

Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising" or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items.

DETAILED DESCRIPTION

FIG. **1** illustrates an electrical device **100** embodying aspects of the invention. In the illustrated construction and in some aspects, the electrical device **100** is a power tool, and, more particularly, a power tool configured to be hand-held during operation (i.e., the electrical device **100** is a power tool designed to be supported by an operator, and not normally supported on a surface, such as a workbench, during operation). In the illustrated construction, the electrical device **100** is a reciprocating saw. It should be understood that aspects of the invention apply equally to any electrical device that includes a SR motor, such as, for example other power tools configured to be hand-held during operation (e.g., drills, circular saws, grinders, reciprocating saws, sanders, caulk guns, jigsaws, screwdrivers, heat guns, impact wrenches, shears, nibblers, rotary hammers, routers, hand planers, plate jointers, rotary tools, etc.), power tools not configured to be hand-held during operation (e.g., miter saws, planers, drill presses, table saws, lathes, etc.) and other types of electrical devices (e.g., washing machines, compressors, blower units, automotive applications, etc.). In the illustrated construction, the electrical device **100** includes a control housing **104**, a drive unit housing **108** and a driven unit housing **112**. In other constructions, more or fewer housing sections may be utilized (e.g., a single housing formed of two corresponding halves).

A first end **116** of the control housing **104** is configured to fit an operator's hand, and a second end **120** of the control housing **104** houses a majority of an electronics package discussed below in more detail. A trigger **124** is actuated by the operator to operate the electrical device **100** by selectively connecting a power source (not shown) to the SR motor of the electrical device **100**. In the illustrated construction, a power cord **128** electrically connects the electrical device **100** to an AC power source. Other constructions may include a battery pack that acts as a DC power source, a combination of an AC and a DC power source, and/or any other type of power source.

The drive unit housing **108** is coupled to the control housing **104** and houses the drive unit (i.e., a SR motor and components associated with the SR motor). The driven unit housing **112** is coupled to the drive unit housing **108** and houses the driven unit. The driven unit of the illustrated electrical device **100** includes a toothed blade **132** which cuts in a reciprocating type motion. The driven unit may be any type of driven unit and shall therefore not be discussed further in detail.

FIG. **2** illustrates a schematic view of a representative SR motor **10**. The SR motor **10** includes a rotor **14** mounted for rotation about an axis **18**, and a stator **38** surrounding the rotor **14**. The rotor **14** includes four rotor poles **22**, **26**, **30** and **34** evenly spaced about the axis **18**, and extending radially outward from the rotor **14** relative to the axis **18**. The stator **38** has an inner surface **42**, and six stator poles **46**, **50**, **54**, **58**, **62** and **66** evenly spaced about the inner surface **42**, and extending from the inner surface **42** radially inwardly toward the axis **18**. FIGS. **3**A and **3**B further illustrate one construction of the rotor **14** in more detail. In one construction, the rotor **14** is constructed of a number of laminations **15** as shown in FIG. **3**C. FIG. **4** illustrates a perspective view of the stator **38** and FIG. **5**A and **5**B further illustrate one construction of the stator **38** in more detail. In one construction, the stator **38** is constructed of a number of laminations **39** as shown in FIG. **5**C. As shown in FIGS. **4** and **5**A, the stator **38** includes a number of apertures **240**, any number of which may extend axially through the stator **38**. In one construction, two diametrically opposite apertures **240***a* and **240***d* include a round shaped cross-section and the remaining four apertures **240***b*, **240***c*, **240***e* and **240***f* include an oblong shaped cross-section. In other constructions, the positioning of the apertures **240**, the shape of the cross-sections of the apertures **240** and/or the number of apertures **240** may vary. In alternative constructions, other types of positioning features could be utilized.

Because the SR motor **10** includes six stator poles and four rotor poles, the SR motor **10** shown in FIG. **2** is referred to as a 6/4 (six stator pole to four rotor pole ratio) SR motor. While the description refers to the operation of the invention in terms of a 6/4 SR motor, it should be understood that any SR motor having any number of stator poles or rotor poles can be utilized as the drive unit in the electrical device **100**.

The SR motor **10** also includes windings or coils **70**, **74**, **78**, **82**, **86** and **90** on the stator poles **46**, **50**, **54**, **58**, **62** and **66**, respectively. The windings **70**, **74**, **78**, **82**, **86** and **90** are made of a conductor of a precise gauge which is wound around the corresponding stator pole **46**, **50**, **54**, **58**, **62** and **66** a precise number of times or turns. The gauge of the wire and the number of turns vary depending upon the application of the SR motor **10**. The description applies equally to any SR motor using any gauge wire or having any number of turns.

The windings **70**, **74**, **78**, **82**, **86** and **90** on diametrically opposite stator poles **46**, **50**, **54**, **58**, **62** and **66**, respectively, are connected in series to form three electrically independent phases **1**, **2** and **3** of the SR motor **10**. In an alternative construction, the windings **70**, **74**, **78**, **82**, **86** and **90** could be connected in parallel to form the three electrically independent phases **1**, **2** and **3**. As shown in FIG. **2**, the windings **70** and **82** on stator poles **46** and **58**, respectively, form pole pairs which together form phase **1**. The windings **74** and **86** on stator poles **50** and **62**, respectively, form pole pairs which together form phase **2**. The windings **78** and **90** on stator poles **54** and **60**, respectively, form pole pairs which together form phase **3**. Because the rotor **14** is made of ferromagnetic material, energizing a particular phase of the SR motor **10** results in the formation of a magnetic attraction between the windings on the stator pole pairs comprising the energized phase and the rotor poles closest to the stator poles of the energized phase. By energizing the phases **1**, **2** and **3** in a particular manner, the rotational direction and speed of the rotor **14** can be precisely controlled.

FIG. **6** illustrates a rotor assembly **130**. The rotor assembly **130** includes a shaft **132** to which the rotor **14** is mounted for rotation about the axis **18**. The shaft **132** rotates in response to rotational forces caused by the rotor **14** in accordance with operation of the SR motor **10** (e.g., in a forward direction and/or in a reverse direction as selectively indicated by the operator of the electrical device **100** (dependent upon the construction of the electrical device **100**)). The shaft **132** is supported for rotational movement about the axis **18** by a first bearing **136** and a second bearing **140**. A fan **144** is also coupled to the shaft **132**. The fan **144** is utilized to dissipate heat from the electrical device **100** as discussed below. As illustrated in FIG. **7**, a magnet hub **148** may also be mounted to the shaft **132**. The magnet hub **148** includes magnet poles M (not individually shown). In one construction, the magnet hub **148** includes eight magnet poles M (i.e., two magnet poles M per rotor pole). In alternative constructions, the magnet hub **148** may include any number of magnet poles M. The magnet hub **148** may further include any number of magnets that include any number of magnet poles M to provide the overall number of magnet poles M of the magnet hub **148** (e.g., to achieve a total of eight magnet poles M, the magnet hub **148** may include eight magnets with eight magnet poles M, or one magnet with **8** magnet poles M, or two magnets with two magnet poles M each and one magnet with four magnet poles M, etc.). The magnet poles M may be utilized, as discussed below, to determine the speed at which the shaft **132** is rotating, the direction in which the shaft **132** is rotating and the position of the rotor **14** with respect to the stator **38**.

FIG. **8** illustrates an exploded view of and FIG. **9** illustrates a side view of the rotor assembly **130**. A shaft tube **152** may be coupled to the shaft **132** radially inward of the rotor **14**. In one construction, the shaft tube **152** may electrically insulate the rotor **14** from the shaft **132**.

FIGS. **10** and **11** illustrate a stator assembly **156** that includes the stator **38**, a rear bell **160**, a terminal board **164** and a front bell **168**. FIG. **12** illustrates an exploded view of and FIGS. **13**A and **13**B illustrate a side view and an end view of the stator assembly **156**.

As shown in FIGS. **14**A, **14**B, **14**C, **14**D, **14**E, and **14**F, the rear bell **160** includes a first side **244**, a second side **248** and a stepped hub **200** having a magnet pocket **204** and a bearing pocket **208**. The first side **244** includes an opening to the stepped hub **200**. The opening allows the magnet hub **148** and the first bearing **136** to pass through the first side **244** into the stepped hub **200**. As shown in FIGS. **15** and **16**, when the electrical device **100** is assembled as discussed below, the magnet hub **148** is encapsulated between the stepped hub **200** and the first bearing **136**. The magnet hub **148** is allowed to rotate in the magnet pocket **204** and the first bearing **136** is seated in the bearing pocket **208** such that no contaminants can reach the magnet hub **148** as discussed below in more detail.

The first side **244** also includes a first annular region **252** which is positioned radially adjacent and outward of the opening to the stepped hub **200**, and a second annular region **256** which is positioned radially adjacent and outward of the first annular region **252**. The first annular region **252** is substantially planar. The second annular region **256** includes a number of spacer blocks **260** that extend axially away from the plane of the first annular region **252** in a direction opposite the direction of the second side **248**. The second annular region **256** also includes a number of contact apertures **264** that allow contacts of the electronics package to pass through. In one construction, the number of contact apertures **264** corresponds to the number of contacts.

In one construction, the second annular region **256** includes six spacer blocks **260***a*, **260***b*, **260***c*, **260***d*, **260***e* and **260***f* which are evenly spaced about the circumference of the second annular region **256**. As discussed above, the positioning features utilized may vary. The spacer blocks **260***a* and **260***d* include apertures **266***a* and **266***d*, respectively. In one construction, the apertures **266***a* and **266***d* include a round shaped cross-section corresponding to the round shaped cross-section of apertures **240***a* and **240***d*. In one construction, the apertures **266***a* and **266***d* do not extend to the second side **248**. The spacer blocks **260***c* and **260***f* include pin members **268***c* and **268***f*, respectively. In one construction, the pin members **268***c* and **268***f* include an oblong shaped cross-section corresponding to the oblong shaped cross-section of apertures **240***c* and **240***f*. In one construction, apertures **240***c* and **240***f* are configured to receive pin members **268***c* and **268***f*. In one construction, the spacer blocks **260***b* and **260***e* are axially shorter than the spacer blocks **260***a*, **260***c*, **260***d* and **260***f*. The spacer blocks **260***b* and **260***e* may be shorter than the spacer blocks **260***a*, **260***c*, **260***d* and **260***f* by an amount corresponding approximately to the thickness of the terminal plate **164**. The spacer blocks **260***c* and **260***f* include a protrusion (i.e., pin members **268***c* and **268***f*) that results in an overall height profile that is taller than the remaining blocks. However, the pin members **268***c* and **268***f* are utilized such that, when the stator assembly **156** is assembled as discussed below, each spacer block **260***a*, **260***b*, **260***c*, **260***d*, **260***e* and **260***f* rests flush against a corresponding surface.

The second side **248** of the rear bell **160** includes an exterior stepped annular wall and a closed end of the stepped hub **200**. The second side **248** also includes the contact apertures **264** and apertures **265**. In one construction, the apertures **265** do not extend to the first side **244**. The aperture **265** may be utilized to retain the printed circuit boards to the rear bell **160**. The second side **248** is surrounded by a circumferentially positioned annular wall **272** that extends axially away from the plane of the first annular region **252** in a direction opposite the first side **244**. The annular wall **272** extends axially such that each printed circuit board ("PCB") of the electronics package is radially enclosed by the annular wall **272** as discussed below. In one construction, the annular wall **272** includes two diametrically opposed flange portions **274**. Each flange portion **274** may includes an aperture **276**. In one construction, the aperture **276** is located on the second side **248** of the flange portion **274** and does not extend through to the first side **244** of the flange portion **274**. The aperture **276** may be utilized to retain the PCBs to the rear bell **160**.

As shown in FIG. **17**A, the terminal board **164** includes an aperture **280**. Radially adjacent and outward of the aperture **280** the terminal board **164** includes an annular region **284**. The aperture **280** is preferably sized such that the annular region **284** substantially similar in size to the second annular region **256** of the first side **244** of the rear bell **160**. The annular region **284** includes a number of cutouts **304***a*, **304***c*, **304***d* and **304***f*. In one construction, the cutouts **304***a* and **304***d* include a recess **305***a* and **305***d*, respectively, having a half-round cross section corresponding to a portion of the round shaped cross-section of the apertures **240***a* and **240***d*. In one construction, the spacing of the cutouts **304***a*, **304***c*, **304***d* and **304***f* corresponds to the spacing of the spacer blocks **260***a*, **260***c*, **260***d* and **260***f* (i.e. the spacer blocks that include the apertures **266***a* and **266***d* and the pin members **268***c* and **268***f*). The annular region **284** includes a first side **292** and a second side **296**. The first side **292** is substantially planar. The second side **294** includes a number of pin members **308***b* and **308***e*. In one construction, the pin members **308***b* and **308***e* include an oblong shaped cross-section corresponding to the oblong shaped cross-section of the apertures **240***b* and **240***e*. In one construction, the apertures **240***b* and **240***e* are configured to receive pin members **304***b* and **304***e*. The second side **296** also includes placement locations **300** for placement of terminal blocks **192**. In one construction, the terminal blocks **192** are attached to the terminal board **164** with an adhesive. In another construction, the terminal blocks **192** are integral with the terminal board **164**. The terminal blocks **192** include female connectors **191**. The female connectors **191** are electrically coupled to representative conductors that make up the stator windings of the SR motor **10**. As discussed further below, contacts of the electronics package engage the female connectors **191** thereby releasably electrically coupling the electronics package to the electrically independent phases. FIGS. **15** and **16** illustrate the releasable engagement. In one construction, the placement locations **300** are spaced such that the spacing of the female connectors **191** in the terminal blocks **192** corresponds to the spacing of the representative contacts that releasably engage the female connectors **191**. In other constructions, the terminal blocks **192** may include male connectors.

Referring to FIGS. **18**A, **18**B, **18**C, and **18**D, the front bell **168** includes a first end **312** and a second end **316**. The first end **312** is configured to be adjacent to the stator **38**. The second end is configured to be adjacent to the gearbox of the driven unit which is housed in the driven unit housing **112**. A circumferentially positioned annular wall **320** connects the first end **312** to the second end **316**. The circumferentially positioned annular wall **320** includes a number of air inlet vents **322**. The air inlet vents **322** may be utilized as part of the heat dissipation techniques discussed below.

The first end **312** includes an annular region **324** radially adjacent and outward of an aperture **328**. The aperture **328** is sized such that the annular region **324** is substantially similar in size to the radially outward portion of the stator core. In one construction, the circumferentially positioned annular wall **320** includes a positioner portion **320***p* that extends axially beyond the annular region **324**. The positioner portion **320***p* of the circumferentially positioned annular wall **320** may be utilized to position the front bell **168** with respect to the stator **38**. The positioner portion **320***p* is located radially outward of the stator **38** when utilized to position the front bell **168** with respect to the stator **38**. The annular region **324** includes apertures **329***a* and **329***d*. In one construction, the apertures **329***a* and **329***d* include a round shaped cross-section corresponding to the round shaped cross-section of apertures **240***a* and **240***d*.

The second end **316** also includes an annular region **332** radially adjacent and outward of an aperture **336**. The aperture **336** is sized such that the annular region **332** is substantially similar in size to the corresponding surface of the driven unit housing **112**. The annular region **332** includes a number of tabs **340**. The tabs **340** include apertures **344** that allow fasteners to pass through which are utilized to position the stator assembly **156** with respect to the drive unit housing **108** and the driven unit housing **112**.

Referring to FIG. **12**, a fan baffle **345** is configured to direct heated air propelled by the fan **144** out of the electrical device **100**. The fan baffle **345** is supported by the annular region **324** and the circumferentially annular wall **320** of the front bell **168**. The fan baffle **345** includes an annular region **348** radially adjacent and outward of an aperture **352**. The aperture **352** is sized such that the annular region **348** is substantially similar in size to the annular region **324**. The annular region **348** includes a triangular shaped cross-section corresponding to the cross-section shape of each blade member of the fan **144**. The fan baffle **345** includes a number of spacer blocks

356 that extend axially towards the annular region 324. In one construction, the spacer blocks 356 are configured such that the air inlet holes 322 are not blocked by the fan baffle 345.

FIGS. 19A-C illustrate a schematic diagram of an electronics package that is utilized to control the operation of the SR motor 10 based on the operator's input using the trigger 124. The electronics package includes a number of low voltage (e.g., a controller and hall effect devices) and a number of high voltage (i.e., power) components. Generally, power components need to be isolated from low voltage components because electrical noise generated by the power components can disrupt the operation of the low voltage components. A technique for reducing the electrical interference caused by the power components is to separate the power components from the low voltage components by enough space on the PCB on which the power components and the low voltage components are mounted such that the degree of electrical interference experienced by the low voltage components does not disrupt the operation of the low voltage components. As discussed above, space considerations of the illustrated electrical device 100 do not allow for such spacing techniques. Accordingly, in one aspect, the invention provides for the use of two PCBs that are stacked, thereby separating the power components from the low voltage components such that the low voltage components operate as intended. The stacked PCBs are shown in FIGS. 15 and 16 which illustrate partial sectional views of the electrical device 100. In other constructions, the components and/or the PCB(s) may be placed alternatively (e.g., some low voltage components placed on a PCB that is perpendicular to a PCB that includes low voltage components and power components), shielding techniques may be utilized to limit the amount of electrical interference received by the low voltage components, and/or other techniques may be utilized to ensure proper operation of the electrical components.

FIG. 20 illustrates a perspective view of a first PCB 169 that is utilized primarily for the low voltage components of the electronics package. The first PCB 169 may be screen printed to indicate the location of the components included on the first PCB 169. The first PCB 169 includes a number of position/speed sensors 193. In one construction, the position/speed sensors 193 are hall effect devices. The position/speed sensors 193 interact with the magnet hub 148 to determine the speed and direction in which the shaft 132 is rotating and the position of the rotor poles 22, 26, 30 and 34 with respect to the stator poles 46, 50, 54, 58, 62 and 66, such that the representative phases 1, 2 and 3 of the SR motor 10 can be energized at appropriate times to effectively operate the SR motor 10. Such determinations may be made by the controller in accordance with techniques generally known in the art. In one construction, the first PCB 169 includes an aperture 196. The aperture 196 corresponds to the size of the stepped hub 200 on the rear bell 160 such that the first PCB 169 can rest against the second side 248 of the rear bell 160.

The aperture 196 of the first PCB 169 may include a number of tabs 212 that correspond to notches 216 in the stepped hub 200 of the rear bell 160. The position/speed sensors 193 are located on the tabs 212 such that the radial distance between the magnet hub 148 and the position/speed sensors 193 is minimal. As discussed above, the magnet hub 148 includes a number of magnet poles M. As the shaft 132 rotates, the rotor 14 and the magnet hub 148 rotate at the same speed as the shaft 132. The position/speed sensors 193 sense the magnet poles M as the magnet poles M pass by each position/speed sensor 193. The position/speed sensors 193 generate a signal representative of what is currently being sensed by the position/speed sensor 193 (e.g., the presence of a north and/or south magnet pole M and the strength of the interaction, or the lack of the presence of a magnet pole M). The controller receives the signal and utilizes the data to determine the speed and direction of the shaft 132 rotation, the position of the rotor 14 with respect to the stator 38 and the energizing pattern of the representative electrically independent phases 1, 2 and 3. In alternative constructions, the method of position/speed sensing could vary (e.g., optical sensing, varied placement of the position/speed sensors 193 (e.g., inboard of the magnet poles M instead of outboard of the magnet poles M such that the signal is obtained from an axial surface of the magnet poles M instead of a radial surface), use of surface mount technology, etc).

FIG. 21 illustrates a perspective view of a second PCB 172 that is utilized primarily for the power components of the electronics package. FIGS. 19A-C include a section 173 (surrounded by a dashed line). The components in the section 173 generally correspond to the power components, and the components outside of the section 173 generally correspond to the low voltage components. The second PCB 172 may be screen printed in a manner similar to that used on the first PCB 169. The second PCB 172 includes a large heat sink 176, a power box 180 (e.g., power transistors and diodes) and storage capacitors 184. The second PCB 172 further includes a number of connectors (not shown) that electrically connect the second PCB 172 to the first PCB 169. In one construction, the connectors provide signals (e.g., a power signal and a ground) to the low voltage components mounted on the first PCB 169.

The second PCB 172 also includes a number of contacts 190 (only one contact 190 is illustrated in FIG. 21). As discussed above, each of the contacts 190 is designed to removably electrically couple the electronics package of the electrical device 100 to a representative stator winding 70, 74, 78, 82, 86 and 90. The illustrated contacts 190 are male connectors. The corresponding female connectors 191 are located in the terminal blocks 192. When the stator assembly 156 is assembled as discussed below, the electronics package is electrically connected to the stator windings 70, 74, 78, 82, 86 and 90 and the controller can control the operation of the SR motor 10 in accordance with generally known techniques.

In one construction, the second PCB 172 includes one contact 190 for each stator winding, or two contacts for each electrically independent phase. A single conductor is utilized to form the stator windings of the pole pair of stator windings that form an electrically independent phase when the number of contacts 190 equals the number of stator windings. That is, for example, a single conductor is utilized to first form stator winding 74 on stator pole 50 and then stator winding 86 on stator pole 62. A portion of the single conductor forms an input to the electrically independent phase 2 and another portion of the single conductor forms an output to the electrically independent phase 2. One contact 190 is electrically coupled to the input, and a second contact 190 is electrically coupled to the output. The controller can then control the operation of that particular phase.

In another construction, the second PCB 172 may include twice as many contacts 190 as stator windings, or four contacts for each electrically independent phase. A single conductor is utilized to form a single stator winding when the number of contacts 190 equals twice the number of stator windings. Each stator winding of the pole pair of stator windings that form an electrically independent phase includes an input and an output. A first contact 190 is electrically coupled to the input of a first stator winding, a second contact 190 is electrically coupled to the output of the first stator winding, a third contact 190 is electrically coupled to the input of a second stator winding and a fourth contact 190 is electrically coupled to the output of the second stator winding. The second and third contacts **190** are electrically coupled to one another via the electronics package to form an electrically independent phase. The controller can then control the operation of that particular phase.

In an alternative construction of the stator assembly **156**, a terminal plate **164** may be provided on each side of the stator **38** or on the side of the stator **38** opposite to that of the illustrated construction. Techniques in accordance with those discussed above may then be utilized to form the electrically independent phases of the SR motor **10**.

It should be understood that the present invention is capable of use with other PCB configurations and that the first PCB **169** and the second PCB **172** are merely shown and described as an example of one such PCB configuration. The illustrated PCB configuration includes two double-sided single-layer PCBs.

For example, as is further illustrated in FIGS. **19**A-C, the electrical device **100** may include a third small PCB (not shown) that includes the components in a section **174** (surrounded by a dashed line). The components in section **174** may be utilized to determine a temperature at a location inside the electrical device **100** (e.g., near the electronics mounted on the heat sink **176**) and may be utilized as part of the heat dissipation techniques discussed below in more detail. In one construction, if the temperature inside the electrical device **100** exceeds a threshold level, the power provided to the electrical device **100** may be automatically limited to ensure the operational parts of the electrical device **100** are not adversely affected by the high temperature.

In one construction, the controller of the electronics package is implemented in a programmable device. The controller may operate through the use of a number of inputs. For example, the controller may receive position and speed data from the position/speed sensors **193** from which the motor speed is computed. The controller may also receive input from one or more devices (e.g., the trigger **124**) which indicate the desired speed of operation as well as the desired direction of rotation (if applicable). Based on the sensed speed and direction and the requested speed and direction, the controller outputs the proper commutation sequence in order to drive the SR motor **10** at the desired speed and direction of rotation. The controller may also receive information regarding the current in the SR motor **10** which can be used to monitor the current for a current overload condition. If such a condition exists, the controller outputs a reduced commutation sequence to limit the current in the windings. The controller may also receive temperature data that is utilized to monitor the temperature of monitored components (e.g. the heat sink **176**, the stator **38**, etc.) for a high temperature condition. If such a condition exists, the controller may output a shutdown command (or alternatively slow the speed of operation) to limit damage to the components of the electrical device **100**.

Heat Dissipation

Heat generated by the electrical device **100** includes heat generated by the electrical components and heat generated by the stator windings. Heat that is generated needs to be dissipated for efficient operation of the SR motor **10**. Typically, active dissipation techniques are more advantageous than passive dissipation techniques.

Power components commonly generate more heat than low voltage components. The heat sink **176** discussed above assists in dissipating heat generated by the power components through passive techniques. The effectiveness of the heat sink **176** can be greatly increased by propelling air across the fins of the heat sink **176** to produce active dissipation. Similarly, components of the SR motor **10** that include windings typically generate much more heat than components that do not include windings. Although the rotor **14** does not include windings, the stator **38** does. The stator **38** therefore adds to the heat generated by the electrical device **100**. This heat must also be dissipated for efficient operation of the electrical device **100**. Again, active dissipation is more effective than passive dissipation.

Accordingly, in one aspect, the invention includes a method and apparatus for propelling cooling air through the electrical device **100** such that heat is actively dissipated. FIGS. **1** and **15** illustrate air intake vents **360** in the control housing **104** of the electrical device **100**. As the shaft **132** rotates, the fan **144** coupled to the shaft **132** rotates and pulls fresh air through the air intake vents **360**. Air entering the air intake vents **360** is cool and can be utilized for the cooling process. Air inside the electrical device **100** is encouraged to continue to travel toward the fan **144**. The air that enters the air intake vents **360** is directed either radially toward the geometry of the heat sink **176** or axially toward the SR motor **10**.

The rear bell **160** axially seals the electronics package from the SR motor **10** and, therefore, air that travels across the heat sink **176** is only allowed to travel radially away from the heat sink **176**. As the air travels radially away from the heat sink **176** it encounters an inside surface of the control housing **104** and is directed axially toward the SR motor **10**.

Air traveling axially toward the SR motor **10** travels between the circumferentially annular wall **272** and an inside surface of the control unit housing **104**. This air can continue to travel down the inside of the housing between the outside of the stator **38** and an inside surface of the drive unit housing **108** or, alternatively, this air can travel radially inward through gaps between the spacer blocks **260**. FIGS. **22** and **23** further illustrate the spaces through which the air can travel. The spacer blocks **260** are configured such that air can travel between the spacer blocks **260** and then axially towards the stator windings. Air travelling axially towards the stator windings travels across the stator windings thereby cooling the stator windings. The air then continues to move axially towards the fan **144**.

Air traveling between the inside surface of the drive unit housing **108** and the stator **38** cools the outside of the stator **38**. As the air approaches the air inlet vents **322**, the air turns radially inward and travels through the air inlet vents **322** and toward the fan **144**. The heated air is then propelled through the fan and out an air outlet vent **364** (FIG. **1**). The air outlet vent **364** vents heated air to the outside of the electrical device **100**. As illustrated in FIG. **1**, the air outlet vent is at the junction of the drive unit housing **104** and the driven unit housing **108**. Air is allowed to reach the air outlet vent **364** through gaps **368** created between the front bell **168** and the drive unit housing **108**. The front bell **168** is positioned adjacent the driven unit housing **112** at tabs **340**, but as illustrated in FIG. **23**, the gaps **368** allow the heated air to reach the air outlet vent **364**. When the shaft **132** is rotating (i.e., when the electrical device **100** is operating and therefore generating heat), cool air is continually pulled in through the air intake vents **360** and heated air is continually pushed out of the air outlet vents **364**. In one construction, the fan **144** is a mixed flow fan that allows for axial and radial flow. In alternative constructions, an axial flow fan or a radial flow fan may be utilized. In alternative constructions, the air passages may be altered to allow for an efficient cooling process.

Tolerance Stack-Up

Manufacturing of a SR motor generally requires that the air gap between the stator **38** and the rotor **14** is small enough that the stator poles **46**, **50**, **54**, **58**, **62** and **66** and the rotor poles **22**, **26**, **30**, and **34** are allowed to interact for efficient operation of the SR motor **10**. Larger air gaps can generally be utilized for efficient operation of the other types of drive units commonly utilized in hand-held power tools. Therefore, the tolerance requirements for an efficient SR motor are generally much fighter than the tolerance requirements for an efficient other type of drive unit (e.g., a universal motor). Despite the potential benefits available through the use of the SR motor **10** as the drive unit for a hand-held power tool, the labor costs associated with producing the SR motor **10** for use in the electrical device **100** are inhibitive when accomplished in accordance with general power tool construction techniques (i.e., with the high tolerance requirements). Accordingly, in one aspect, the invention provides a construction of the electrical device **100** that reduces tolerance "stack-up" as is generally produced during power tool assembly in accordance with general power tool construction techniques. Tolerance stack-up typically does not result in power tool operation problems when the power tool being assembled incorporates a drive unit other than a SR motor because of the use of a larger air gap.

General power tool construction techniques include coupling the rotor of the drive unit to the gearbox of the driven unit and coupling the stator of the drive unit to the housing of the power tool. The invention incorporates a reduced tolerance stack-up design though the elimination of a number of the levels of tolerance. For example, the stator assembly **156** is not coupled to any portion of the housing (e.g., the control housing **104**, the drive unit housing **108** and/or the driven unit housing **112**) for the purpose of aligning the stator assembly **156**. The stator assembly **156** is only positioned inside the housing of the electrical device **100** for the purpose of protecting the internal workings of the electrical device **100**. One end of the rotor assembly **130** is aligned with respect to the stator assembly **156** such that the rotor **14** and the stator **38** are allowed to interact for efficient operation of the SR motor **10**.

The rotor assembly **130** is assembled as discussed above. The stator assembly **156** is assembled according to the following process. The stator **38** including the terminal plate **164** is positioned between the front bell **168** and the rear bell **160**. The terminal plate **164** is positioned such that pin members **308***b* and **308***e* are received by apertures **240***b* and **240***e* of the stator **38** and the cutouts **304***a* and **304***d* including the recesses **305***a* and **305**d, respectively, are aligned with the corresponding apertures **240***a* and **240***d* on the stator **38**. The rear bell **160** is positioned on the side of the stator **38** including the terminal plate **164**. The spacer blocks **260** of the rear bell **160** are positioned such that the pin members **268***c* and **268***f* of spacer blocks **260***c* and **260***f* are received by apertures **240***c* and **240***f* of the stator **38** and the apertures **266***a* and **266***d* of spacer blocks **260***a* and **260***d* are aligned with the corresponding apertures **240***a* and **240***d* on the stator **38**. When the terminal plate **164** and the rear bell **160** are aligned in such a manner, the spacer blocks **260***b* and **260***e* rest flush against the terminal plate **164** on the first side **292** of the terminal plate **164** opposite the pin members **308***b* and **308***e*, spacer blocks **260***a*, **260***c*, **260***d* and **260***f* rest flush against the stator **38** and the second side **296** of the terminal plate **164** rests flush against the stator **38**. In one construction, the spacer blocks **260***b* and **260***e* actually do not rest flush on the terminal plate **164** but float with respect to the terminal plate **164** such that no tolerance stack-up is added due to the terminal plate **164**. The spacer blocks **260***b* and **260***e* may be a fraction of an inch (e.g., 0.004 inches) smaller than the gap they are utilized to fill to achieve this float. Inclusion of the cutouts **304***a*, **304***c*, **304***d* and **304***f* on the terminal plate **164** and the reduced height profile of spacer blocks **260***b* and **260***e* results in no tolerance stack-up attributable to the terminal plate. The positioner portion **320***p* of the circumferentially annular wall **320** is positioned radially outward of the stator **38**. Such placement positions the annular region **324** adjacent to the stator **38**. The apertures **329***a* and **329***b* are aligned with the corresponding apertures **240***a* and **240***d* on the stator **38**. As illustrated in FIG. **12**, two bolt members **372***a* and **372***b* are positioned through the apertures **329***a* and **329***b* of the front bell **168**, through the apertures **240***a* and **240***d* of the stator **38**, through the cutouts **304***a* and **304***d* (including the recess **305***a* and **305***d*) of the terminal plate **164** and into the apertures **266***a* and **266***d* of the rear bell **160** wherein the bolt members **372***a* and **372***d* are terminated. As the bolt members **372***a* and **372***d* are fastened, the components of the stator assembly **156** are frictionally engaged with one another. The fan baffle **308** is placed in the front bell **168** resulting in an assembled stator assembly **156** (e.g., the stator assembly illustrated in FIG. **12**). In one construction, the bolt members **372***a* and **372***b* are threaded into the apertures **266***a* and **266***d*. In alternative constructions, the stator assembly **156** may be held together with other types of fasteners.

After the stator assembly **156** has been assembled, the rotor assembly **130** is coupled to the stator assembly **156** by pressing the end of the shaft **132** including the magnet hub **148** and the first bearing **136** into the stepped hub **200**. In one construction, a tolerance ring is placed radially adjacent and outward of the first bearing **136** in the bearing pocket **208**. The tolerance ring is utilized in one aspect to compensate for any thermal expansion of the rear bell **160**. The other end of the rotor assembly **130** is then coupled to the driven unit housed in the driven unit housing **112**. The combination of the rotor assembly **130** and the stator assembly **156** is positioned in the housing of the electrical device **100**. Tabs **340** and apertures **344** are utilized to position the combination in the drive unit housing **108** and the driven unit housing **112**.

The electronics package is then inserted as discussed below. After the electronics package is inserted, the remaining portions of the housing are assembled and the electrical device **100** is readied for use.

The method and apparatus for assembling the electrical device **100** reduces tolerance stack-up such that the rotor **14** and the stator **38** interact for efficient operation of the SR motor **10**. Additionally, the method and apparatus for assembling the electrical device **100** are accomplished with labor costs that are competitive in the market. These techniques may be useful in any electrical device **100** that utilizes a SR motor **10**.

Self-Contained Electronic Package

The electrical device **100** includes an electronics package that is releasably engaged by the remaining components of the stator assembly **156**. Such a construction is advantageous for assembly and future replacement of the electronics package. The characteristics of the SR motor **10** may necessitate replacement of the electronics package at some time. The electronics package may be replaced because of failure of all or a portion thereof of the electronics package and/or to provide enhanced motor operation through use of an improved electronics package (e.g., new software for position/speed sensing). The housing can be removed and the electronics package unengaged from the terminal blocks **192** simply by removing a number of fasteners. A replacement electronics package can then be quickly engaged by the terminal blocks **192** and the housing reassembled. This configuration may also be advantageous in applications of SR motors outside hand-held power tools.

The first PCB **169** is coupled to the rear bell **160** through the use of two fasteners (not shown). The fasteners are inserted past two cutouts **376** in the first PCB **169** and into the apertures **265** wherein the fasteners terminate. In one construction, the fasteners are threaded into the apertures **265**. In alternative constructions, the first PCB **169** may be coupled to the rear bell **160** using other methods. The second PCB **172** is then electrically coupled to the first PCB **169** via the connectors that deliver the signals such as power and ground, and via the contacts **190** that engage the female connectors **191** of the terminal blocks **192**. The second PCB **172** is coupled to the rear bell **160** through the use of two fasteners (not shown). The fasteners are inserted through two apertures **378** in the second PCB **172** and into the apertures **276**. In one construction, the apertures **378** have a round shaped cross-section corresponding to the round shaped cross-section of apertures **276**. In one construction, the fasteners are threaded into the apertures **276**. In alternative constructions, the second PCB **172** may be coupled to the rear bell **160** using other methods. Once the first PCB **169** and the second PCB **172** are coupled to the rear bell **160**, the rest of the electrical device **100** can be assembled and readied for operation.

Magnet Encapsulation

Encapsulation of the magnet hub **148** is advantageous because the magnet hub **148** is therefore not in an environment that may include foreign particles such as metal shavings, and the like, that could become magnetically or otherwise coupled to the magnet poles M of the magnet hub **148**. Foreign particles such as metal shavings and dirt may interfere with the accuracy of determinations of the speed at which the shaft **132** is rotating, the direction in which the shaft **132** is rotating and the position of the rotor **14** with respect to the stator **38**.

As discussed above, the magnet hub **148** is encapsulated when the stator assembly **156** and the rotor assembly **130** are combined. When the stator assembly **156** and the rotor assembly **130** are combined, the magnet hub **148** is placed in the magnet pocket **204** and the first bearing **136** is seated in the bearing pocket **208**. The shaft **132** is thereby allowed to rotate about the axis **18** via the first bearing **136** (and the second bearing **140**) while the outside surface of the first bearing **136** remains frictionally engaged with the bearing pocket **208**. The magnet hub **148** rotates with the shaft **132** in the magnet pocket **204** and is used to determine speed and direction of the SR motor **10** as discussed above.

Magnet Alignment

The positioning of the magnet poles M with respect to the rotor poles **22**, **26**, **30** and **34** which the magnet poles M are intended to represent is important when the interactions between the magnet poles M and the position/speed sensors **193** are used to determine the position of the rotor poles **22**, **26**, **30** and **34** with respect to the stator poles **46**, **50**, **54**, **58**, **62** and **66**. The positioning of the magnet poles M is important for determining position of the rotor **12** with respect to the stator **38** because the process of energizing each of the electrically independent phases **1**, **2**, and **3** at the appropriate time is needed for efficient operation of the SR motor **10**. Accordingly, since the interactions between the magnet poles M and the position/speed sensors **193** are utilized for, among other things, position sensing, the invention provides an apparatus and a method for aligning the magnet poles M with respect to the rotor poles **22**, **26**, **30** and **34** the magnet poles M represent. The positioning of the magnet poles M with respect to the rotor poles **22**, **26**, **30** and **34** which the magnet poles M represent is not particularly important when the interactions between the magnet poles M and the position/speed sensors **193** are used only to determine the speed at which and/or the direction in which the shaft **132** is rotating.

FIG. **24** illustrates a fixture **220** for aligning the magnet poles M with respect to the rotor poles **22**, **26**, **30** and **34** which the magnet poles M represent. The fixture **220** includes a number of magnets **224**. The magnets **224** are preferably spaced in accordance with the spacing of the rotor poles **22**, **26**, **30** and **34** (e.g., evenly spaced about the axis **18**). In alternative constructions of the rotor **14**, the fixture **220** would preferably be correspondingly altered. The magnets **224** are orientated such that the magnet poles M of the magnet hub **148** are attracted to the magnets **224** when the magnet hub **148** is inserted in the fixture **220** (i.e., north poles of magnet hub **148** are attracted to south poles of magnets **224** and south poles of magnet hub **148** are attracted to north poles of magnets **224**). The fixture **220** includes a number of pole members **228**. The pole members **228** accept two diametrically opposite rotor poles (e.g., rotor poles **22** and **30**). In one construction, the magnets **224** are circumferentially aligned with respect to the pole members **228** such that the magnet poles M on the magnet hub **148** are aligned with respect to the magnets **224** such that the position of each magnet poles M is known with respect to a leading edge or a trailing edge of the rotor pole which the corresponding magnet pole M represents. When the position of the magnet pole M being sensed is correlated to a position on the rotor pole which the magnet pole M represents, the controller can determine the optimum time to energize each of the electrically independent phases **1**, **2** and **3**.

To align the magnet poles M of the magnet hub **148** with respect to the rotor poles **22**, **26**, **30** and **34** the magnet poles M represent, the magnet hub **148** is first placed in a recess **232** of the fixture **220**. In one construction, the magnet hub **148** is placed in the recess **232** such that the magnet portion of the magnet hub **148** (see FIG. **10**) is facing downward in the recess **232**. The recess **232** includes a spring biased member **236**. The spring biased member **236** supports the magnet hub **148** such that the magnet poles M align with respect to the magnets **224** thereby rotating the magnet hub **148**. In one construction, all of the magnet poles M are identically sized and the magnet hub **148** can be initially positioned in any orientation as discussed above. Once the magnet poles M of the magnet hub **148** have reached equilibrium, a partially assembled rotor assembly **130** (e.g., the rotor assembly **130** illustrated in FIG. **6**) is inserted into the fixture **220** such that the first bearing **136** side of the shaft **132** is facing downward in the fixture **220**. The end of the shaft **132** is inserted into the aperture **232** of the magnet hub **148** and the partially assembled rotor assembly **130** is forcibly pushed downward in the fixture **220**. The spring biased member **236** retracts in response to the force and the magnet hub **148** is coupled to the end of the shaft **132**. The rotor assembly **130** (e.g., the rotor assembly **130** illustrated in FIG. **7**) can then be used to assemble the electrical device **100** as discussed above.

Alternate Constructions

FIGS. **25**, **26**, **27**, **28**, and **29** illustrate an alternate construction of a portion of the electrical device **100**. The alternate construction includes an electronics module (not shown) that is coupled to the electrical device **100** by at least one lead or connector.

FIGS. **25** and **26** illustrate a stator assembly **400** that is similar to the stator assembly **156** except that the stator assembly **400** does not include the terminal board **164** or the rear bell **160**. The stator assembly **400** instead includes a rear structure **404** that supports the bearing **136** of the rotor assembly **130**. The magnet hub **148** is allowed to rotate in a fashion similar to that of the construction discussed above.

FIGS. **27**, **28**, and **29** illustrate partial assemblies of the alternate construction. A PCB **408** is coupled to the rear structure **404**. The PCB **408** includes position/speed sensors that interact with the magnet poles of the magnet hub **148** as discussed above. The rear structure **404** includes a number of apertures **412***a-f* that correspond to the apertures **240***a-f*.

FIGS. **30**, **31**, **32**, **33**, **34**, **35**, **36**, **37**, and **38** illustrate an alternative construction of an electrical device **1000**. In the illustrated alternative construction, the electrical device **1000** is a circular saw. The electrical device **100** and the electrical device **1000** are substantially identical with respect to the disclosed aspects. Common components of the electrical device **100** are indicated by the same reference numerals in the one-thousand series. Although the electrical device **100** and the electrical device **1000** have an obviously different appearance, the integration of the SR motor of the electrical device **1000** and the electronics package utilized to operate the SR motor of the electrical device **1000** is almost identical to the integration of SR motor **10** and the electronics package utilized to operate the SR motor **10**. The component parts of the rotor assembly **1130** and the stator assembly **1156** may vary in shape and size, but the function is similar to that discussed above with respect to the rotor assembly **130** and the stator assembly **156**.

FIG. **30** illustrates a perspective view of the electrical device **1000**. FIGS. **31** and **32** illustrate perspective views of the rotor assembly **1130**. FIGS. **33** and **34** illustrate perspective views of the stator assembly **1156**. FIG. **35** illustrates a partial sectional view of the electrical device **1000** illustrated in FIG. **30**. FIG. **36** illustrates a perspective view of a second PCB **1172**. FIGS. **37** and **38** illustrate perspective views of the electrical device **1000** with a portion of the housing removed.

Thus, the invention provides, among other things, an electrical device that includes a SR motor. One or more independent features and independent advantages of the invention are set forth in the following claims:

We claim:

1. A power tool comprising:

a first housing including a grip portion engageable by a hand of an operator, the housing being supportable by the operator during operation of the power tool;

a second housing configured to support a switched reluctance motor operable to drive a tool element to work on a work piece, the switched reluctance motor including a stator assembly comprising

a stator defining an opening and including an axis through the opening,

a rear bell positioned adjacent to the stator along the axis, the rear bell including a first side, a second side, and an aperture, the first side defining a substantially centralized and stepped recess, the second side defining an annular wall and a hub, and

a rotor assembly having a shaft, the rotor assembly including

a rotor mounted on the shaft and configured to be received within the opening of the stator, and

a magnet hub mounted on the shaft configured to be received within the centralized recess of the first side of the rear bell; and

a single modular electronics package including a circuit board configured to fit within the recess, the circuit board having at least one contact arranged to fit through the aperture and adapted to electrically and physically connect to the switched reluctance motor when the first housing is coupled to the second housing, the single modular electronics package being removably coupled to the switched reluctance motor.

2. The power tool as claimed in claim **1**, wherein the electronics package includes an electronics package housing configured to support the electrical components.

3. The power tool as claimed in claim **2**, wherein the electronics package housing is constructed of an electrically nonconductive material.

4. The power tool as claimed in claim **2**, wherein the electronics package housing substantially seals the electrical components from the switched reluctance motor.

5. The power tool as claimed in claim **1**, wherein the electrical components include low voltage electrical components and power electrical components operable to receive power from a power supply.

6. The power tool as claimed in claim **5**, wherein the power electrical components receive an alternating current power from an alternating current power supply.

7. The power tool as claimed in claim **5**, wherein the power electrical components receive a direct current power from a rechargeable battery.

8. The power tool as claimed in claim **5**, wherein the power electrical components include power transistors, wherein the switched reluctance motor includes windings supported on the stator, and wherein the power transistors are operable to energize the windings.

9. The power tool as claimed in claim **5**, wherein the power electrical components include a storage capacitor operable to store at least a portion of the power received from the power supply.

10. The power tool as claimed in claim **5**, wherein the low voltage electrical components include hall effect devices, and wherein the hall effect devices sense rotation of the magnet hub.

11. The power tool as claimed in claim **5**, wherein the low voltage electrical components include speed sensors, and wherein the speed sensors sense a speed of rotation of the shaft.

12. The power tool as claimed in claim **5**, wherein the low voltage electrical components include position sensors, and wherein the position sensors sense a position of the rotor relative to the stator.

13. A power tool comprising:

a housing including a grip portion engageable by a hand of an operator, the housing being supportable by the operator during operation of the power tool;

a switched reluctance motor positioned inside the housing and operable to drive a tool element to work on a work piece, the switched reluctance motor including a stator assembly comprising

a stator defining an opening and including an axis through the opening,

a rear bell positioned adjacent to the stator along the axis, the rear bell including a first side, a second side, and an aperture, the first side defining a substantially centralized and stepped recess, the second side defining an annular wall and a hub, and

a rotor assembly having a shaft, the rotor assembly including

a rotor mounted on the shaft and configured to be received within the opening of the stator, and

a magnet hub mounted on the shaft configured to be received within the centralized recess of the first side of the rear bell; and electrical components operable to control the operation of the switched reluctance motor, the electrical components being arranged as a single modular electronics package, the single modular electronics package being removably coupled to the switched reluctance motor;

wherein the electronics package includes first and second printed circuit boards, and

wherein the first and second printed circuit boards fit within the recess and at least one of the first and second printed circuit boards includes a contact extending through the aperture and being adapted to electrically and physically connect to the switched reluctance motor.

14. The power tool as claimed in claim **13**, wherein the electrical components include low voltage electrical components and power components operable to receive power from a power supply, and wherein the first printed circuit board includes the low voltage components and the second printed circuit board includes the power components.

15. The power tool as claimed in claim **14**, wherein the first printed circuit board is spaced from the second printed circuit board to reduce electrical interference generated by the power components on the low voltage components.

16. A power tool comprising:

a housing including a grip portion engageable by a hand of an operator, the housing being supportable by the operator during operation of the power tool;

a switched reluctance motor positioned inside the housing and operable to drive a tool element to work on a work piece; and

electrical components operable to control the operation of the switched reluctance motor, the electrical components being arranged as a single modular electronics package, the electronics package including at least one contact configured to fit through an aperture in a rear bell of a stator assembly, the contact adapted to directly electrically and physically connect to the switched reluctance motor, the single modular electronics package being removably coupled to the switched reluctance motor; and

wherein the switched reluctance motor includes

a stator assembly positioned relative to the housing, the stator assembly including a stator defining an opening and including an axis through the opening,

the rear bell being positioned adjacent to the stator along the axis, the rear bell including a first side, a second side, and the aperture, the first side defining a substantially centralized and stepped recess, the second side defining an annular wall and a hub,

a shaft rotatable relative to the stator about the axis, and

a rotor connected to the shaft for rotation with the shaft relative to the stator, the rotor configured to be received within the opening of the stator, and a magnet hub mounted on the shaft configured to be received within the centralized recess of the first side of the rear bell, and

wherein the electronics package includes a plurality of circuit boards surrounded by the annular wall of the second side of the rear bell, the electronics package configured to support an end portion of the shaft for rotation about the axis.

17. The power tool as claimed in claim **16**, wherein the modular electronics package includes an electronics package housing configured to support the electrical components which substantially seals the electrical components from the switched reluctance motor.

18. The power tool as claimed in claim **16**, wherein the modular electronics package includes a first printed circuit board and a second printed circuit board, wherein the first printed circuit board includes low voltage components operable to receive power from a power supply and the second printed circuit board includes power components operable to receive power from a power supply.

* * * * *